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1. Introduction

This document is the final report for the third year of a three-year extension of National Aeronautics and Space Administration (NASA), Office of Earth Science (OES), grant NAG5-3620 which was awarded in December 1998, titled: "Remote Sensing Information Science Research Group". Work on this grant primarily focuses on the conduct of both fundamental and applied research by the Information Sciences Research Group (ISRG), of the Remote Sensing Research Unit (RSRU), at the University of California, Santa Barbara (UCSB). This year's research continued the shifting of activities into more applications oriented research areas. These include topics where fundamental, applied and activities exhibiting operational implementation and/or commercial potential of remote sensing and other geospatial data and information products continue to show promise.

Presented herein is a summary of research activities the grant period of 15 December 1999 through 30 June 2001. This end date was an extension from the original completion date of 14 December 2000. The research described in this document was substantially completed during the original funding period (12/15/99 – 12/14/00). Throughout the life of this research grant, support has been contingent upon a yearly evaluation and approval. We have previously submitted progress reports for each grant year and each of these progress reports have also included our research proposal and suggested budget for the following year.

The original Principal Investigator of this research grant, Dr. John E. Estes, passed away in March, 2001. His role as Principal Investigator was assumed by Dr. Keith C. Clarke, Professor of Geography at the University of California, Santa Barbara. Mr. Joseph Scepan, Senior Staff Researcher, continued as Co-principal investigator of this research.

ISRG/RSRU research is conducted by faculty, research staff, and students at the University of California, Santa Barbara,. In the past ISRG research has also been conducted with researchers at affiliated institutions and organizations. Over the past several years our research has shifted to focus on improving our ability to employ advanced information systems with new space-borne observation data. Our particular focus was on Terra satellite sensor systems (formerly called EOS - the Earth Observing System) for basic, applied and commercially oriented research in the Earth Science Enterprise (ESE). The goal of our research continued to be the improvement of our understanding of the overall science and applications potential of ESE data and information products. During this period we paid close attention to data products produced by the Landsat 7 (ETM+) system that supports Earth science applications and the extended commercial remote sensing user community. ISRG/RSRU researchers have worked to accomplish this goal through research as well as fundamental and applied examination and evaluation of advanced information science techniques and methodologies.

Collaborative research continued to be conducted under NAG5-3620. A number of new collaborative efforts had been initiated and conducted during previous years and some of this research was partially supported from other sources. We feel that this type of "leveraged" funding and the additional research input and perspective into the research conducted under this grant have provided real benefit to NASA. During this final contract period, new and continued collaboration was planned with the following institutions and organizations:

- NASA Stennis Space Center
- U.S. Geological Survey's Earth Resources Observation System (EROS) Data Center (EDC)
- Geographical Survey Institute (GSI) of the Ministry of Construction of Japan
- Digital Earth
- The Consortium for International Earth Science Network (CIESIN)
- Global Spatial Data Infrastructure
- Globexplorer
- Global Initiatives, Inc.
- MapFactory - Hammond, Jensen, and Wallen (HJW)

Other activities under this research agreement continued or were expanded. These include:

- Applications and EOSDIS extension
- Potential commercial applications of OES science data products
- Performance metrics development activities

- Surveys of applications of remotely sensed data in Europe and Asia
- Global mapping and thematic accuracy validation efforts

Portions of our efforts related to thematic validation will continue to be developed as separate studies by the Earth Science and Solar System Exploration Division of Johnson Space Center and the United States Geological Survey.

With this renewal of NAG5-3620, ISRG/RSRU will work in close collaboration with its associated institutions to strengthen and deepen its fundamental and applied information system education, research, dissemination, and coordination activities for NASA's Earth Science Enterprise (ESE).

1.1. Background

The world's population continues to increase. Along with this increase in global population, there is a continuing need for improved systems and techniques capable of acquiring, integrating, and analyzing information concerning the major components of the Earth's ecosystem. Parts of the ecosystem are cause for enormous concern. Worldwide fish harvests have peaked and major fisheries are threatened. Fresh water sources are increasingly polluted. The world's forests are shrinking at a rate estimated to be on the order of one acre per second. Croplands appear to have increased only two percent over the last decade. All of these events are occurring while millions of human beings are being added to the Earth's population each month.

The general public and our elected representatives continue to express concern over the status and trends of environmental indicators. Poverty, pollution of fresh water, greenhouse gases and their effect on global warming, famine and the status of women are all of concern to national and international policy makers and to the public at large. The loss of biodiversity associated with deforestation, urbanization and the destruction of wetlands is of particular concern. Issues such as the ozone hole, tropical deforestation and the loss of biological diversity have become household phrases. Yet, there is increasing political and economic concern regarding the socioeconomic implications of both environmental preservation, and conservation. Politicians and the Administration are asking for more accurate, up-to-date information concerning the potential commercial, economic, and societal benefits that can accrue from the astute application of advanced remote sensing and information systems technology.

Responding to this need, NASA, Office of Earth Science (OES), Applications Commercialization and Education (ACE) Division is expanding its already important role in education and outreach aimed at kindergarten through high school (K-12) and college levels as well as at policy makers and the general public. NASA is stressing the importance of understanding the Earth as a unique functioning biotic system. A key to achieving this understanding is the effective use of data and information from current and planned space based public and private civil satellite remote sensing programs.

We believe that the use of such data and information can be facilitated by the expeditious development of advanced geospatial information systems, techniques and methodologies. These systems, techniques and methodologies can and will expand the uses of ESE, Terra, and EOSDIS science and applications data and information products. If these products are to be utilized to their fullest potential, future geospatial information systems must be integrated with the National Information Infrastructure (NII - the national information superhighway), and the National Spatial Data Infrastructure (NSDI). In addition, these national geospatial information systems should fit seamlessly into the evolving Global Spatial Data Infrastructure (GSDI). This GSDI effort is central to the development of Digital Earth. Activities associated with the development of this GSDI are gaining considerable momentum at this time, and ISRG researchers, including Dr. John E. Estes, Director of this research until his death, are intimately involved in these efforts. Dr. Estes served as Chair of the International Steering Committee for Global Mapping (discussed in more detail below), and a Member of the Executive Committee of the GSDI effort. Before his death, Dr. Estes was also asked to serve on the Advisory Board of Globexplorer. Until his death, Professor Estes continue to work to insure that ESE data and information and NASA-led Digital Earth activities were fully considered in all Global Mapping and GSDI activities.

Data and information from Earth orbiting satellites and ground based data and information systems are critical as we attempt to improve to develop enlightened policies concerning the management of the Earth system. Achievement of the long-range goal of understanding the earth as a functionally integrated system requires farsighted fundamental and applied research directed towards improving remote sensing information extraction, storage, retrieval, and dissemination techniques and methodologies. We must more effectively move to improve our ability to translate scientific understanding into efficient operational implementation. Achieving this goal will also require educating people at all levels, both in public service and in private industry to the wide range of applications of these systems for measuring, mapping, monitoring, and modeling the current and future status of the biosphere, hydrosphere, atmosphere, and lithosphere. In addition, as we attempt to understand the potential commercial uses of OES science data products, it will also mean that we will need to expand our contacts in the operational user and business community as well. We have already begun to do this, making contacts with data producers, value-added firms, and end users.

Previously, ISRG and affiliated personnel conducted more fundamental information system related research in a number of specific areas directly related to the achievement of the long-range goal stated above. These are:

- User requirements for spatially referenced data
- Browse systems for large spatial databases
- Improved data and information dissemination methodologies
- Knowledge based geographic information systems for integration of remotely sensed and other data
- Data standards and heterogeneous computing environments

ISRG has been actively involved in education, support and coordination efforts related to these activities.

In our more recent efforts we have taken a much more applications oriented tack. In keeping with the expressed desire of Code YO personnel to demonstrate the transition from fundamental research to operational implementation we have moved towards examining ways to demonstrate the applications potential of Earth Science Enterprise (ESE) sensor systems and scientific advances. In these efforts, ISRG/RSRU personnel have been working with researchers at a number of institutions and organizations in the U.S. and abroad. These institutions and organizations include:

- University of Maryland, Baltimore County, MD
- Georgia Institute of Technology, Atlanta, GA
- Boston University, Boston, MA
- University of Virginia, Charlottesville, VA
- University of Idaho, Moscow, ID
- University of Maryland, College Park, MD
- University of Wisconsin, Madison, WI
- University of Florida, Gainesville, FL
- Consortium for International Earth Science Information Networks, New York, NY
- University of Bonn, Germany
- University of Osnabruck-Vechta, Vechta, Germany
- University of Padua, Italy
- Hiroshima Institute of Technology, Hiroshima, Japan
- Miyazaki University, Miyazaki, Japan
- United States department of Transportation, Washington, D.C.
- The U.S. Geological Survey EROS Data Center (USGS/EDC), Sioux Falls, SD
- NOAA Coastal Systems Center, Charleston, SC
- The Geographical Survey Institute of the Ministry of Construction of Japan,
- Australian Land Information Group, Canberra, Australia
- Joint Research Center, European Economic Community (JRC/ECE), Ispra, Italy, and,

Previously, UMBC researchers have worked with ISRG/RSRU personnel on a study of the socioeconomic and biophysical factors that have influenced the development of the Baltimore-Washington Corridor. We have also completed our direct work with UMBC personnel on Remote Sensing Core Curriculum development and Conference on Remote Sensing Education activities. Core curriculum development activities in the past also

involved researchers at the University of South Carolina with support from personnel at Clark University and the Georgia Institute of Technology. The RSCC is important as we train the K-16+ students who represent the future generation of users of Earth observing satellite data. This core curriculum development effort was very important as we examine ways to extend uses of the products of the Earth Observing System Data and Information System (EOSDIS) in the broader applied and commercially oriented remote sensing data user community.

Work with the Cooperative Fish and Wildlife Research Unit, of the Biological Resource Division of the U.S. Geological Survey at the University of Idaho involved ways to improve our understanding of the information required by decision-makers trying to preserve global biodiversity. This work was directed at the up-date and search for a home for the Managed Areas Database (MAD). The MAD database contains information on the relative levels of protection afforded by Federal, State, Local and Non-governmental Organization's (NGO) managed lands throughout the United States. This important data set was developed in support of the Geographic Analysis Program (GAP) of the then National Biological Survey. Recent discussions have progress to a point where it now appears that the International Consortium for Earth Science Information Networks will take over responsibility for the MAD database.

Our work with USGS, EDC, Boston University, University of Maryland, College Park, University of Virginia, Charlottesville, University of Bonn, Germany and JRC/EEC has focused on improving our understanding of the data and information required for the validation of thematic data products at regional, continental and global scales. This work was directly supported by the OES Code YS, Land Cover Land Use Change (LCLUC) Program. In addition, ISRG research with EDC and The University of Maryland, College Park is examining innovative ways to employ the Shuttle and International Space Station for validation of land cover change and the study of ephemeral events. This research has been conducted in conjunction with work underway with personnel of the International Soil Reference and Information Center at Wageningen, Netherlands to improve the ability to scale trace gas fluxes. ISRG/RSRU and EDC personnel participated in a workshop and wrote a major paper on the importance of land cover in this type of effort.

We also are continuing our work with the Geographical Survey Institute of the Ministry of Construction of Japan that involves improving our understanding of, and access to, global scale maps at scales of 1: 1km (approximately 1:1 million) and larger. This work is ongoing and being conducted under the auspices of the International Steering Committee for Global Mapping (ISCGM). This group includes the heads of some fourteen National Mapping Organizations including those of the United States, Japan, Great Britain, France, Canada, and China. A major aspect of this work is improving our access to high quality, globally consistent land data sets. In this effort we were supported by and work closely with Dr. Eric Anderson of the United States Geological Survey, who is currently stationed at the NOAA Coastal Systems center in Charleston, South Carolina.

We also worked with personnel of the Hiroshima Institute of Technology on advanced image processing techniques. In addition, RSRU/ISRG also hosted a visiting scholar from Miyazuki University, Japan and an employee of the Geographical Survey Institute (GSI) of the Ministry of Construction, Japan. The GSI employee focused on improving his understanding of the challenges inherent in large area, thematic map accuracy validation.

ISRG Researchers were also involved in a number of ways with the new United States Department of Transportation's (USDOT) remote sensing research initiative. USCB is the lead of a consortium that includes the University of Florida, the University of Wisconsin and several private firms that is examining the application of remote sensing to the analysis of transportation infrastructure. Under NAG5-3620, RSRU/ISRG was directly involved in this effort. In addition to being involved in the UCSB portion of this effort, Professor Estes served on the Advisory Board of the University of New Mexico consortium. This consortium is examining the use of remotely sensed data to study hazards to transportation.

For the current reporting period under this grant we have focused on fundamental, applications and commercially oriented research. Specific emphasis has been on education, outreach, and coordination activities directed at improving our use of satellite remotely sensed and correlative data within an information systems context. We have also begun efforts to understand what types of applied research projects the international remote sensing community is pursuing.

Other recent research under this grant have included:

- The efforts around EOSDIS extension and user model development
- Operational and commercial applications of OES science data products
- Multi-scale, multi-temporal, multi-spectral image analysis for land management
- Multi-image registration
- Statistical processing and visualization of continental-scale climatic data
- Remote sensing / GIS integration for landform analysis and mapping

Research on these activities is being carried forward by ISRG/RSRU personnel and progress within each of theses topics during this reporting period is discussed in more detail in the sections that follow.

The results of ISRG/RSRU researcher is published regularly in reviewed journals and other publication outlets including symposia, conference, and workshop proceedings. The September, 1999 Special Issue of the journal of the American Society for Photogrammetry and Remote Sensing, *Photogrammetric Engineering and Remote Sensing* was devoted to the Global Land Cover Map Validation effort lead by ISRG/RSRU researchers. ISRG personnel also make presentations at national and international scientific meetings. ISRG investigators have also helped organize conferences, workshops, training courses and reviews that have helped NASA Earth Science and education personnel and the international mapping; environment and development communities improve their data and information systems capabilities. These activities have also helped these organizations gain insights into key data related problems and opportunities. In the conduct of these research and support activities ISRG/RSRU faculty and researchers have developed an extensive network of professional contacts in both the national and international research, applications, and educational communities involved in many aspects of information science research and development and global environmental change activities.

Research at ISRG/RSRU has also focused on the integration of existing research and educational activities at UCSB and the initiation and conduct of a number of research activities with a variety of NASA centers. ISRG researchers have also worked on research and technology background assessments directed towards the design and implementation of EOSDIS for NASA Headquarters, NASA Centers, and contract personnel. In addition, UCSB and grant related personnel have been involved with the EOS Data Systems Panel, the EOSDIS Review Group (ERG) and the National Polar Orbiting Environment Satellite/NASA Polar Platform (NPOES/NPP) activity. ISRG personnel have served, or are serving on the following:

- Earth System Science and Applications Advisory Committee (ESSAC),
- Applications, Commercialization and Education Division Steering Committee,
- The Space Station Data User Working Group,
- The Space Station Operations Science Management Working Group
- Space Station Science and Applications Advisory Subcommittee (SSSAAS - renamed the Space Station Utilization Advisory Subcommittee – (SSUAS), and
- The International Forum on the Scientific Uses of Space Station (IFSUSS)

In the area of data and information development ISRG personnel have worked in the U.S. with the User Working Group for the Socioeconomic Distributed Active Archive (SEDAC). Professor Estes remained a member of the SEDAC User Working Group until his death. ISRG researchers were also part of the Science and Applications Information Systems Working Group. At the international level ISRG researchers have worked on data and information development issues with these agencies and groups:

- The United Nations Environment Program, Division of Environmental Information, Assessment and Early Warning
- The United Nations Environment Program Global Resources Information Database (UNEP/GRID)
- The United Nations Development Program Asia-Pacific Region, Data and Information Systems Offices
- United Nation Education Scientific and Cultural Organization
- United Nations Institute for Training and Research
- The World Conservation Monitoring Center

- International Soil Reference and Information Center
- The International Steering Committee for Global Mapping
- Global Spatial Data Infrastructure Executive Committee

At the National Academy of Science/National Research Council level, ISRG personnel have been active in the following committees, Boards and Commissions:

- The Committee on Data Management and Computation (CODMAC)
- The Committee on Planetary Biology and Chemical Evolution
- The Committee on the Mapping Sciences
- The Space Applications Board
- The Space Studies Board
- The Board on Naval Studies
- The Commission on Physical Science, Mathematics and Applications
- The Commission on Earth and Geosciences

ISRG researchers have also been involved in a number of other national and international panels and working groups, including:

- The Global Change Peer Review Panel for the United States Geological Survey
- The Environmental Protection Agency EMAP/Landcover Review Panel
- The National Oceanic and Atmospheric Administration (NOAA), Coast Watch Peer Review Panel
- NASA's Landsat Pathfinder Science Working Group
- The International Institute of the Environment
- The Scientific Committee on Problems of the Environment
- The Consortium of International Earth Science Information Networks (CIESIN)

As a result of these collaborations, UCSB is currently an integral part of the operations of a North American Node of the United Nations Environment Program, Global Resources Information Database (UNEP/GRID). We are cooperating in this effort with NASA, and the United States Geological Survey (USGS) EROS Data Center in Sioux Falls, South Dakota.

In addition to these efforts, ISRG professors and researchers have working with other national and international organizations in examining macro-scale ecological and land cover issues. These organizations include:

- The Scientific Committee on Problems of Environment (SCOPE),
- The United Nations Education Scientific and Cultural Organization (UNESCO),
- United Nations Environment Program (UNEP),
- United Nations Development Program (UNDP),
- International Geosphere-Biosphere Program (IGBP); specifically, the Validation Working Group (VWG) for the DISCover Global 1 Kilometer Land Cover Project,
- IGBP's Land Cover Working Group,
- World Conservation Monitoring Center (WCMC)
- The Environmental Protection Agency (EPA),
- The U.S. Agency for International Development (USAID),
- The Famine Early Warning System Program (FEWS),
- The Space Agency Forum (SAF),
- The Committee on Earth Observation Satellites (CEOS),
- Global Climate Observing System/Global Terrestrial Observing System (GCOS/GTOS), and
- The US Global Change Research Program (USGCRP).

ISRG research and educational activities in connection with all of these efforts have had both a basic and an applied cast. A major result of this work was the publication by UNESCO and SCOPE of a document for the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro. This publication

produced in three languages was coordinated and developed by ISRG researchers Dr. Estes and the late Dr. Jeffrey L. Star.

In March 2000 ISRG researchers attended the GSDI and ISCGM meetings in Capetown, South Africa as well as a Global Mapping Forum meeting held in Japan in November, 2000. Dr. Estes, supported by the Geographical Survey Institute of the Ministry of Construction, Japan, presented a paper on Global Mapping at the 15th United Nations cartographic Conference for Asia and the Pacific in Kuala Lumpur, Malaysia in April, 2000.

We believe that the research described in this document has been significant and that our results have been of direct benefit to NASA's Office of Earth Science, in general, and The Digital Earth and Applications Commercialization and Education Division (Code YO) in particular. We also believe that our applied research has provided the global remote sensing user community with an improved understanding of the broad diversity of applications of data and information from Earth Science Enterprise data and information including those derived from the Terra and the Landsat 7 Systems as well as commercial 1-meter class satellites.

1.2. Research Objectives

The primary research objectives of this research was to:

1. Improve understanding of public sector operational and commercial applications potential of Earth Science Enterprise (ESE) satellite remote sensing data and information.

2. Provide outreach to inform the Earth science remote sensing user community, environmental planners, resource managers, educators, public policy decision-makers and the general public of the basic and applied research and public sector and commercial potential of advance satellite remote sensor systems.

3. Facilitate the implementation of a broad-based remote sensing applications research program to the benefit of the applications user communities and the public at large, via research, education and outreach.

ISRG/GSRU researchers have continued to forward the transition of Earth Science results to the broad remote sensing applications user community. We have extended our fundamental and applied research to address issues related to operational applications, including global land cover mapping, biodiversity, and expanded applications and commercial potential of Terra System and other civil land observing satellite systems data and information products. We have also placed emphasis on work with the State and Local government user community, as well as on work directed at applications at the national and international level. Finally, this research has had the goal to demonstrate to the broad user community the operational and commercial potential inherent in the latest ESE satellite remote sensing data and information products.

2. Progress in Research Associated With NASA NAG5-3620 (ESTES)

Section 2 of this document presents detailed summaries of research activities accomplished under this Research Grant during the period (15 December 1999 through 14 March 2001).

2.1 OES Applied and Commercial Research Activities

Research into the synergy between NASA science and commercial and applications related entities has been a continuing focus of our activities. In previous work, we have shown that much of the NASA EOS science data has the potential to benefit a wide array of users. We have also shown that NASA science can benefit from the ventures of the commercial satellite consortiums whose products have, at least preliminarily, shown that they can be a useful tool from which the scientist can draw data and information. We continue to build on the previously developed matrices by which specific EOS instruments may be used in a commercial marketplace for specific applications and applied sciences. Periodically we continue to update these application areas as new studies warrant due to the changing nature of the remote sensing marketplace and operational practices.

Previously, the two primary benefactors of NASA EOS data products, the Agriculture, Forestry, and Rangeland industries and the State and Local government users have been a focus of our applications related research. Due to the successful launch of the Agriculture, Forestry, and Rangeland NRA, our efforts have focused more closely on the State and Local Government initiative. The new Agriculture, Forestry, and Rangeland projects will be monitored through our Metrics activities. In addition, integration between NASA and commercial satellite imagery for the benefit of science as well as applications and operations has been and continues to be examined closely. Data integration will at such time be explored and demonstrated if possible to provide potential benefit, as we believe it will, for both science and applications related endeavors.

2.1.1 Applications Program History and Assessment

To date, our current and continuing applications related research includes two focused activities.

1. *Assess the current state of the remote sensing applications related projects within NASA.* With the development of an Applications, Commercialization, and Education Division, it is important to understand the current state of the programs within OES that may apply and benefit this division. There is currently a decentralized set of independent efforts that may be directly related to applied sciences and outreach that need to be assessed. The creation of the Earth Science Applications Research Program Metrics Database occurred as a direct result of this research effort. The Government Performance Results Act of 1993 dictates that the value of US Government sponsored research activities to the Citizens of the United States must be determined. Typically, metrics such as these have followed the academic discipline known as infometrics or bibliometrics. These types of metrics are developed through the publishing and tracking research papers and their effect on their discipline by following their citings in other works. Our research into metrics goes beyond these forms in order to more adequately measure the impact of applied remote sensing research on the user community at large. We have recently received the data from the second year of this project.

Metrics Summary (of Reported)	
Projects Reporting	37
Presentation Materials	30
Annual Budget	$17,128,101
Matching Funds	$14,478,656
Paid Employees	208
Products	623
Journal Articles	49
Proceedings Articles	167
Press Mentions	919
Onsite Visitors	65,945
Offsite Exposure	300,330
Undergraduate Degrees	35
Masters Degrees	35
PhD Degrees	4
Datasets Delivered	238,510
Web Hits (1 year)	50,522,302

2. Through this research, we have continued to refine the Metrics Questionnaire that probes the Inputs, Outputs, Outcomes, and Impacts of the Remote Sensing Applications Projects associated with the ESARP. Through a solicitation of the ESARP Principle Investigators, we received responses from 37 of these PI's documenting their research in terms of these four main categories. While a significant set of the total, we are also working to solicit the responses of those PI's that have not participated to date. The metrics data that we have received in previous years have been used to develop products as needed for the ESARP program.

3. *Continue to document and assess the applications potential of OES data products that will be delivered through EOSDIS, the various ESIP's, DAAC's, and RESAC's.* Our continuing research into the commercial applications of EOSDIS science data products was expanded to assess the applications potential of a number of other 'deliverables' by NASA from their remote sensing efforts. To accomplish this effort, we have solicited a number of products from the ESARP Principle Investigators. Specifically, we have received outreach materials for each of the ESARP projects. This includes graphical summaries of each product describing the user community, the user needs, the products and processes, and the utility of their research. In addition, through the use of the metrics database described above, we have developed a comprehensive database of the different products and processes that are being developed through funding by the NASA ESARP.

2.1.2. OES Extension and User Outreach

During this reporting period ISRG researchers have performed studies and conducted workshops that have been directly related to and provided input for several NASA research programs as to research direction and user outreach. The ISRG has also made progress in reaching a wide variety of users at both a professional and educational level. These activities include:

1. Follow-up research into the applications of EOS science data products which has been used to introduce some key concepts towards the development of an Applications, Commercialization, and Education (ACE) Strategic Plan at NASA. Our continued research in this field has updated and modified as necessary the Operational and Commercial Applications Potential of EOS Science Data document that is used as introductory material and an established baseline for many activities including the International Applications Effort.

2. Update of the database documenting all the ESARP projects that included applications area as defined by the ACE strategic plan, by state, and by sub-program. This model has been previously adopted by the ACE division and we have provided continued input to assist in keeping the ESARP programs current.

3. Hosting many classes of secondary school (Grades 6-8) students visiting UCSB, and providing tours of our research facility and demonstrations of remote sensing projects and technologies.

4. Participated in numerous plenary meetings with NASA ACE Division leaders, and the ESARP program manager to discuss and advise on the direction and strategy of these two entities.

2.1.3. Recommendations and Collaborative Activities

We have continued to provide relevant information and data to the new Applications, Commercialization, and Education Division relevant to their policy, programs, and products. Several factors have enabled ISRG to accomplish this.

- Extrapolation of various scenarios based on previous and ongoing ISRG research
- Knowledge of previous and ongoing NASA programs and research initiatives
- Feedback from the user community
- An understanding of the needs of the public and private user community developed through previous research as well as comprehensive publication assessment

We have continued to assess the remote sensing user community. Previous research shows conclusively that access to remote sensor data, ease and power of computing and manipulation, and total utility cost have all improved significantly since the first datasets have become publicly available. A key objective of this component of our research program is to quantify the suitability and usage of remotely sensed data and their derived OES data products so as to better track the user community and provide statistics which will help in the outreach by NASA and others into the global community. Through the analysis of the ability of the user community, the suitability of the OES data products as delivered by a number of programs, and a comprehensive look at the past, present, and future of the applications, outreach, and technology transfer programs within NASA, we believe that we have provided information that will greatly benefit the current user community, increase the number of users of remotely sensed data who were previously unaware of the benefits of remote sensing, and improve the OES and Applications and Outreach Divisions understanding of the needs of this user community.

Based on the research currently being conducted within the framework of the EOS program, there is growing evidence that demand for government sponsored remote sensing data products will increase. We continue to believe that there are three primary reasons for this expected increase. These may be addressed under the headings of 1) Improved Technology; 2) Reduced Cost; and 3) Broader Applications Potential.

1) Improved Technology

The technological focus of this research is the EOS suite of instruments and their science data products. These instruments, by design, will provide data at a high level of accuracy that has been determined to be critical to the scientific mission of OES. Though launched, the first major satellite of the EOS suite (Terra) has yet to make it's way into operational usage. All are expected to be online shortly, however MODIS is still in beta testing, as is ASTER. Only MISR is producing operational data at this point. The EOS instruments will provide several critical technical improvements:

- Improved spatial, spectral, temporal, and radiometric resolutions
- Improved level of sensor calibration
- Improved fusion of data products between sensors

Instrument performance specifications have been developed based upon requirements set down by science program leaders. For this reason, they have a value to their respective science user communities that will be greater than any comparable system. It is the assumption that the quality of the science data products generated will meet the accuracy levels that have been deemed necessary to perform to their individual scientific mission goals.

2) Reduced Cost

Through the technological improvements outlined above (operating under a more enlightened government data policy), we can demonstrate the second primary reason for a stronger demand for remote sensing data products: reduced cost. The costs associated with remote sensing are essentially based upon three factors; human resources, cost of data, and cost of processing. For the purpose of this research, there is no observation regarding the cost of human resources needed to do the applications listed in this report. The pricing structure of EOS data has is based on the particular data source and delivery mechanism, however based on the pricing sheet these costs are nominal, ranging from Free (for the FTP of MODIS and ASTER data) to $600 a scene for Landsat data.

Additionally, the cost of user processing has dramatically decreased. Moore's Law states that ability to process data on a microchip doubles approximately every 18-24 months. In fact, we have seen the exponential growth in processing power over the last 30 years. As a result, the computing costs necessary to use remotely sensed data are much less of a driving factor determining whether or not an application will be economically viable. A steady increase in capability of software necessary for remote sensing has also been observed. Currently, remote sensing analyses can be accomplished on a timely basis using only relatively inexpensive personal computing equipment and free image processing software. This was not the case as recently as 10 years ago.

Computational ability has been one of the factors in examining the costs of using this data in previous reports. This is becoming less and less of an issue as almost all computers can do basic image interpretations adequately. The newest technological issue driving the lowering costs and increased accessibility and usage of the data is the proliferation of broadband internet connections. Using data compression and even faster speeds which are becoming available, it is obvious that the near-instant access to data is well within our grasps.

3) Broader Applications Potential

The potential applications of EOS science data products (as shown in this as well previous NAG5-3620 research) are the result of lengthy searches of remote sensing literature. Throughout the literature there is the observation that remote sensing applications are being continuously discovered, improved, and tested. From this scientific work, there is a continually expanding knowledge base from which commercial applications may be drawn. The potential to apply this ongoing research in an operational setting increases with the advancement in the understanding of the utility of remotely sensed data.

Most scientific research does not attempt to weigh the economic viability of the individual applications. Clearly this is a necessary step in furthering this work towards making the decisions that may affect the utility of EOS data products for the outlined commercial applications. In addition, this research addresses only peripherally one of the key elements of the EOS program, which is the tight integration and compatibility of data products across multiple instruments and platforms. Previous work in remote sensing commercial application has shown few multi-sensor investigations. The study of the utility of multi-sensor applications may provide an even stronger case for the usage of EOS as a commercially viable data product.

Through a strong commercial applications research program, the OES program can be strengthened as a whole. For the data users this work provides information with sufficient time for a commercial interest to determine whether EOS data will be suitable to their particular needs with enough planning time to implement policy decisions. For the EOS science, EOS instrument, and EOSDIS teams, this report may have limited effect on the earliest platforms such as EOS TERRA. Through this work and continuing applications research, however, they may be able to equip the following missions to providing stronger commercially valuable data products.

Based upon our research to date directed toward this topic, we conclude the following:

- A broad user community exists for remote sensing technology and this community can be directly supported by EOS Science data products. The broadband revolution we are currently experiencing will allow contact, information, and data exchange unavailable previously.

- NASA should continue its efforts to establish and aggressively implement a commercial strategy and applications development program through the expansion of such programs as applications oriented NRA and CAN efforts.

- Efforts need to be made to begin the exploration of the synergy between EOS science data products and the existing and planned commercial 1-meter class private sector datasets to improve the temporal, spectral, and radiometric properties of these datasets for the benefit of the application.

In the broadest sense there can be no doubt of the commercial potential of remotely sensed data. This has been more than adequately demonstrated for more than three-quarters of a century. The true operational applications potential of satellite remote sensing has neither been adequately demonstrated nor fully realized. NASA has over its history made a number of attempts to promote the applications of land satellite data, but problems with perceived continuity of data, pricing and technology readiness have been obstacles for marked development. Realization of the applications potential of EOS data will not be easy nor will it be inexpensive, as considerable research and develop will be required. Such efforts would be significantly enhanced if creative mechanisms for fostering cooperation research between academia, industry, and government agencies could be developed and implemented.

2.1.4. International Applications Research Effort

The expansion of ISRG applications research into the international arena has involved much the same approach as the analysis of domestic remote sensing applications. International civil and commercial remote sensing applications thrusts were to be compared between the United States and international nations with the objective of detailing the major current activity thrusts of applied public sector and commercial terrestrial remote sensing by international organizations, agencies, and consortiums. Upon identification of the principal international applications thrusts, a "gap assessment" was to be preformed comparing the U.S. commercial and civil applications program versus the results of the international research. Previous funding from this grant produced a defined set of 20 applications categories, based on domestic applications research. These applications were utilized to evaluate the potential of Earth Observing System data acquisition systems. In order to make the results of the international research compatible for evaluation with the U.S., it was decided to use the same applications categories.

After initial research was conducted, it became clear that the proposed tasks needed to be refined in order to make a product that was both robust and useful. The survey and interview process with foreign organizations and agencies were complex and demanded some sensitivity to the constraints of the commercial environment. Some officials from commercial and civil entities were understandably not anxious to divulge sensitive financial and business data.

The first adjustment in the research program called for the exclusion of airborne remote sensing data acquisition systems. The airborne data included both conventional aerial photography and the more advanced radar, thermal, and optical scanning systems flown on aerial platforms. It was our feeling that consideration of the space borne element independent of the airborne systems would facilitate a greater understanding of the potential of space detection systems in fulfilling the specific data requirements for various applications. The nature of airborne and satellite data with respect the spatial, spectral, and temporal resolution is often dramatically different. By separating the two (i.e. satellite and airborne acquired data), it is easier to evaluate the strengths and weaknesses of satellite data, and to make recommendations as to how further sensor development should proceed.

The second change from our original research concept, called for the evaluation of large geographic regions rather than specific international nations. We have focused our attention on "space nations", or those nations utilizing space derived data products for various forms mapping, policy making, and development. These nations have been aggregated into two specific regions, Europe, and Asia. For our classification Russia has been grouped with Europe, and India has been grouped with Asia -- Figure 2.1.4(a).

Finally, because of the difficulty we have encountered in prioritizing international applications thrusts, we have turned our attention away from the comparison with the United States results, and focused exclusively on Europe and Asia. In the future, the international results can still be compared with similar work previously focused on potential domestic applications of EOS systems data products.

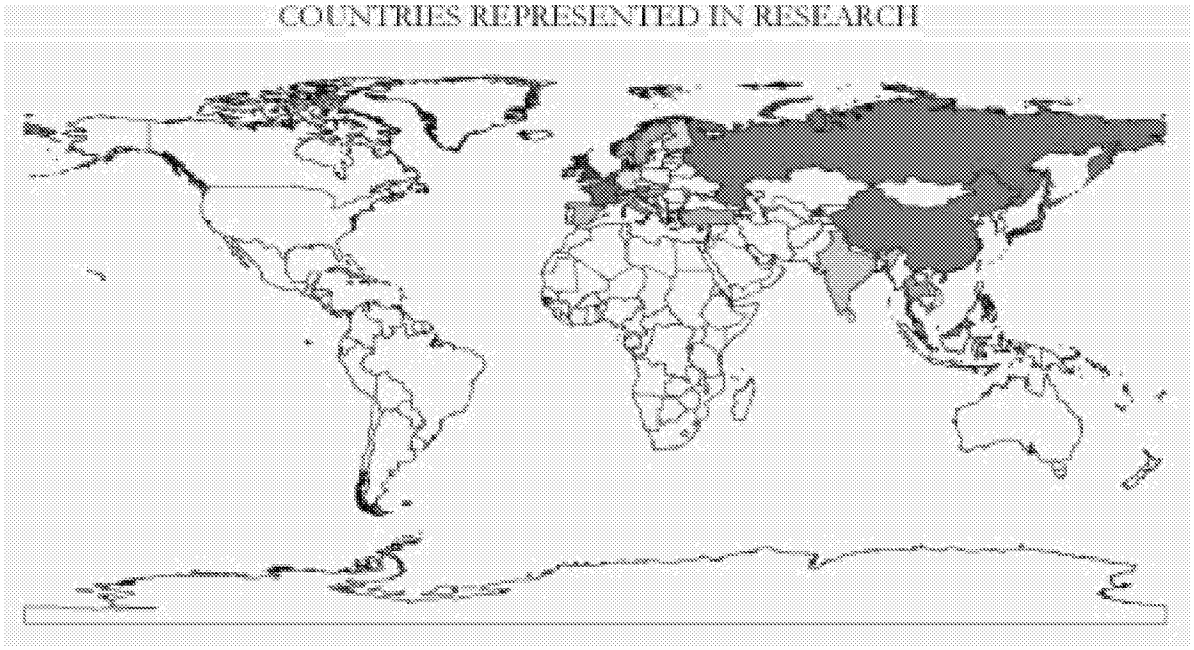


Figure 2.1.4(a). Nations participating in International Remote Sensing Applications Study

International cooperation between European and Asian nations and the United States will continue to grow. It is necessary to understand the needs of our foreign partners in order to develop a strong global economic community. The United States has invested a substantial amount of financial resources developing various space borne remote sensing data acquisition systems, and has become increasingly interested in providing both new and archived data to foreign nations in order to recover some of the investment and to promote future market development.

The twenty applications categories listed below are an outgrowth from research completed in 1997 by Michael Lawless as part of a study of commercial applications potential for Earth Observing System (EOS) data products. Consequently, the definitions developed and described hare are not specific to European and Asian applications, but rather are general in nature. Some references to European or Asian specific applications emphasis in each category are included where appropriate to more tightly couple these definitions to the types of activities in these regions of the world.

1) Economic Development and Conservation

Economic Development and Conservation consists of any segment of commercial or public domain that is concerned with developing methods for or planning sustainable economic development (Estes et al., 1994). Of primary concern are the detection, monitoring, and mitigation of environmental impacts caused by development. Examples include, engineering firms responsible for major social infrastructure development, large commercial land developers, and utility companies. More specifically, the loss of wildlife habitat related to anthropogenic factors is of major concern, because it indicates overall environmental quality. In India, researchers have been using Landsat Thematic Mapper (TM) imagery to map potential Sambar (*Cervus unicolor*) habitat in order to evaluate the vigor of various national parks (Porwal et al., 1996).

2) Urban and Regional Planning

Urban and Regional Planning personnel, both public and private, make critical decisions that impact the environment, socioeconomic conditions, and infrastructure for populated areas. These include, but are not limited to, estimates of urban expansion and population growth, surveying, automated cartographic production capabilities, geographic information systems (GIS) and data base

management assistance, and other technical functions required for the urban planning process. Infrastructure issues such as modeling potential runoff to sewer systems, placement of telephone and high-tension power lines, and site selection for telecommunications towers or industrial facilities often require the use of detailed land use or 3-dimensional terrain models (Halounova, 1992; Maathuis et al., 1999). To this end, remotely sensed data is often a cost-effective and efficient tool. Remotely sensed data is also useful for the analysis of raw materials availability, potential routing information, nuclear power sites, and locations of surface geologic faults when used in conjunction with existing seismological GIS data (Katti et al., 1993).

3) Mapping, Charting, and Geodesy

The *Mapping, Charting, and Geodesy* category incorporates a wide range of mapping activities. Remotely sensed data can be employed to generate map products ranging in scales as large as nations, to regional and local firms producing and distributing finer scale road maps and atlases. This user community includes both public and private entities, active in acquiring, archiving, producing, or distributing geospatial data in analog or digital form. Mathematical emphasis is inherent. Specific applications include terrain modeling, geodetic surveying, and feature extraction. Remotely sensed data can also be useful for the generation of a variety of base cartographic products. For example, fine-scale imagery can be utilized to automatically extract linear features, such as street / road networks, for specialized cartographic tasks (Couloigner and Ranchin, 2000). The multispectral characteristics exhibited by many electro-optical data acquisition systems allows for the classification of a diverse range of surface types, and can be utilized as a cost-effective method for creating detailed thematic maps.

4) Land Use and Land Cover

Land Use and Land Cover data provides some of the most fundamental knowledge concerning a region's territory, and are essential to most global change research activities, including assessing current global environmental conditions, and simulating future environmental scenarios that ultimately lead to public policy development (Campbell, 1997; Loveland et al., 2000). The *Manual of Photographic Interpretation* defines *Land Use* as the utilization of land to fulfill human needs, either in a formal economic sense, or in a broader sense of functional relationships among humans, and between humans and the environment. *Land Cover*, in its narrowest sense, often designates vegetative cover, either natural or anthropogenic, or sometimes its absence. In a broader sense, land cover designates visible evidence of land use, to include both vegetative and nonvegetative features – tropical forest, snow or ice, barren land, wetlands, and urban features all constitute land cover (Campbell, 1997).

5) Agriculture

The *Agriculture* application category includes all parties, both public and private, involved with the growth, management, and prediction of agricultural products. Users include farmers, agrochemical producers, and commodities traders, all of which depend upon, or make profitable use of, weather prediction, yield estimates, and multitemporal monitoring for various forms of analysis and modeling. The *Manual of Photographic Interpretation* identifies six specific components of agricultural applications: crop identification, crop condition assessment (both biotic and abiotic), farm management, rural development, change monitoring, and research applications. Specific applications include: enforcement of quota restrictions, collecting agricultural statistics, soil properties, and irrigation system engineering / management (Schotten et al., 1995; Abderrahman and Bader, 1992).

6) Forestry

The *Forestry* application category includes government agencies (e.g. Forest Service), researchers, consulting firms, and commercial logging operations incorporating the use of remote sensing derived data products for forest stand mapping and inventory, timber harvest planning, stress and disease detection, and estimations of forest biomass, wood volume, and crown size. Foresters use remotely sensed data to classify tree species, locate access roads and property boundaries, determine bearings and distances, and measure areas (Avery and Berlin, 1992; Fazakas et al., 1999). Multitemporal remote

sensing imagery can be used for studies of change detection and monitoring of disease and parasite encroachment, as well as the quantification of the extent and severity of damage to stands from wind and salt stress caused by large-scale weather events, such as Hurricane Hugo in September of 1989 (Cablk et al., 1994; Green and Cosentino, 1996).

7) Rangeland

The *Rangeland* application category includes all parties, both public and private, responsible for the planning, leasing, monitoring, and management of range. The *Manual of Photographic Interpretation* defines *Range* as land that supports vegetation suitable for grazing (Jacoby, 1989; Driscoll et al., 1997). It is any land that supports native and/or naturalized herbaceous and / or shrubby vegetation; it includes natural grasslands, shrublands, savannahs, desert, tundra, alpine, coastal and inland marshes, and, in some instances forested lands. *Rangeland* is naturally and artificially regenerated land areas where herbaceous and / or shrubby species prevail. The land is managed with little input in terms of irrigation or fertilizer or both. Range management comprises range inventory, range monitoring, range condition, and range trend (Driscoll et al., 1997). In addition to active management, there are numerous environmental concerns including biodiversity loss, desertification, unnatural wind and water erosion, and irreparable damage due to overuse (Casimir and Rao, 1998).

8) Emergency Management

The *Emergency Management* application category is concerned with the information technology required to assist decision-makers in the prediction, analysis, and response to natural or man-made crises. Emergency response teams and aid organizations can use remotely sensed data for damage assessment and recovery operations. Natural disasters include, but are not limited to, earthquakes, volcanic eruptions, mass movements (e.g. landslides, avalanches), and severe weather events. Man-made, or man-induced crises include, but are not limited to, warfare, large-scale industrial accidents, and humanitarian operations (post-conflict rehabilitation and reconstruction activities). Remotely sensed data have been used for operational monitoring of marine petrochemical spills, vegetation classification for fire prevention and fuel mapping, and near real-time detection of fire development with AVHRR (Maselli et al., 1996; Airey et al., 1997; Pozo et al., 1997; Pavlakis et al., 1996; Pedersen et al., 1996).

9) Transportation

The *Transportation* application category includes public and private agencies, engineers, and consultants who are employed in the construction, management, or operation of various public transit facilities (e.g. highways and toll roads). The *Manual of Photographic Interpretation* identifies four components of transportation planning studies: assessment of transportation corridors, monitoring street conditions, urban traffic studies, and parking studies. Remotely sensed data, especially at fine scales, provides transportation planners complete views of potential routes, as well as information for classification and modeling of potential problem zones. Of additional concern is the movement of materials (e.g. oil, gas, water, etc.).

10) Geology

The *Geology* application category incorporates the exploration and extraction activities generally associated with commercial industry active in the management of mining, petrochemicals, and other terrestrial natural resource operations. Mineral extraction includes open-air mining for various minerals and chemicals, terrestrial oil production, and precipitate chemical processing operations. Remotely sensed data is routinely used for identifying and mapping landforms, drainage patterns, structural features such as faults and folds, and rock or lithologic units (Avery and Berlin, 1992). Other geological applications include detection and development of hydroelectric and geothermal resources. To a lesser degree, are those government agencies and public / private constituents whose concern is environmental protection, analysis, and mitigation related to ongoing or previous exploitation or extraction activities (Schmidt and Glaesser, 1999).

11) Weather and Climate

The primary users within the *Weather and Climate* application category are government and private weather prediction, monitoring, and tracking services. The ability to understand and accurately predict severe weather conditions is fundamental to protection of property and public safety. Specific applications include prediction / detection of fog areas and fog dissipation, prediction of monsoon onset, cloud classification, convective air mass classification, and estimations of precipitation and cloud moisture content (Lachlan-Cope and Turner, 1997; Pankiewicz, 1997; Anthis and Cracknell, 1999; Feidas et al., 2000). The near real-time temporal resolution and coarse spatial resolution of NOAA's AVHRR sensor, are particularly well suited for monitoring growth and movement of large weather systems in every hemisphere. Additionally, AVHRR has also been shown to be useful for correlating vegetation and precipitation to define eco-climates (Maselli et al., 1996).

12) Air Quality

The *Air Quality* application category incorporates all of the technical functions involved in the process of monitoring and managing air quality at local, regional, and national levels. Monitoring, management, and enforcement of air quality regulations require cooperation between multiple personnel in both the public and private sectors. Environmental policies often require private industry to comply with strict air pollution standards. Various remote sensing techniques have been shown to be useful for the detection and regulation of air quality standards. Specific air quality applications include the detection or measurement of atmospheric aerosols, surface UV radiation, ozone, and actinic flux. European researchers have successfully applied SPOT imagery to calculate the dispersion and deposition of road-generated dust caused by automobile traffic (Keller and Lamprecht, 1995).

13) Water Quality

The *Water Quality* application category includes the technical functions involved in monitoring and analysis of surface and subsurface fresh and coastal water quality. Regulating and observing fresh and coastal water quality is principally the responsibility of public agencies at local, regional, and national levels. Private industry may also be involved as commercial contractors to perform various analyses functions or to participate in the mitigation of polluted or degraded water bodies. Specific water quality applications include pollution detection, mapping water body and watercourse pollutant migration, thermal pollution monitoring, sedimentation concentration estimates, and pollutant runoff detection. Although quantitative water quality measurements often require *in situ* sampling, remotely sensed data can serve as a valuable supplemental data source (Oron and Gitelson, 1996). In particular, thermal pollution is difficult to detect by *in situ* sampling, because many substances rapidly diffuse in water. Thermal remote sensing data is perhaps the best way to monitor thermal plumes and detect point sources (Berghe, 1993; Nelson et al., 1991).

14) Water Resources

The *Water Resources* application category includes all parties, both public and private, responsible for the exploitation, analysis, management, and preservation of water resources. Remote sensing of rivers, lakes, and wetlands is used in specific applications ranging from defining and monitoring flood plains, rates of erosion, wetland extent, and circulation. Hydrologic variables that are potentially available from remote sensing include: soil moisture, snow water equivalent, infiltration, precipitation, soil hydraulic properties, evapotranspiration, frozen soils, surface temperature, and spatial variability within drainage units (Weisnet and Wagner, 1997). Efficient water management is vital to many regions of the world, particularly urban and arid areas. Locating, developing, and monitoring water resources is essential to the support of, or the understanding of, the limits to growth in such areas. In mountainous regions, snow depth and snow extend are critical components of water resource management. Passive microwave can be used to quantify such parameters due to the ability of the radiation to penetrate cloud cover and snow pack (Saraf et al., 1999).

15) Fisheries

The *Fisheries* application category includes public and private personnel exploiting marine and freshwater fish resources, as well as the management and analysis of the impacts the fishing industry has on the environment. Specific applications include the quantification of sea surface temperatures, ocean dynamics, currents, biota, and other relevant parameters (Ramos et al., 1996, Narayana et al., 1995). Nighttime OLS (Operational Linescan System) visible-near-infrared channel imagery from the Defense Meteorological Satellite Program (DMSP) has been used to correlate fishing fleet lights with sea surface temperatures. Certain species of fish have been shown to gather at boundary areas between warm and cold currents. OLS composite imagery may provide useful information for monitoring fishing fleets as well as for fishery resource management (Cho et al., 1999).

16) Marine

The *Marine* application category includes parties, both public and private, that manage, monitor, and analyze those marine (e.g. oceans, coastal zones, salt-water bays, etc.) resources not included in the *Fisheries* application category. This incorporates offshore minerals exploration and exploitation, as well as ocean transportation and ship routing. Specific marine applications include studies of ice pack conditions and ice flows, near-shore sediment transport, sea-mammal census, ocean color, current, sea surface temperature, upwelling, bioluminescence, kelp and other marine plants, detection of marine pollutants, including but not limited to, iron-acid waste, human waste, natural oil and petrochemical seepage, ship trail clouds, and other phenomena (Bardey et al., 1999; Clark and Boyce, 1999; Cracknell, 1999; Dahdouh-Guebas et al., 1999; Dowdeswell et al., 1996). Sea ice, which forms regularly during winters in the high latitudes, can severely impact marine traffic and navigation. To keep major ports open for trade all year, Sweden and Finland operate several icebreakers that rely upon SAR imagery for information and forecast of sea ice formation, drift, and deformation (Hakansson et al., 1995; Herland and Berglund, 1995).

17) Recreation and Tourism

The *Recreation and Tourism* applications category incorporates parties, both public and private, responsible for planning, development, and management of natural areas which are primarily dedicated to leisure use. Specific recreation applications include service-oriented activities such as sport fishing, guided hunting, and wilderness excursions, as well as large commercial theme parks, regional parks or lakes, natural preserves, and other attractions whose preservation, management, or marketing could benefit from the use of geospatial data. Travel agencies have also used remotely sensed imagery for world-wide-web vacation planning applications.

18) Information and Intelligence

The *Information and Intelligence* application category includes both public and private constituents involved with the collection, analyses, and distribution of remotely sensed data relevant to local, national, and global events or phenomena. National governmental intelligence agencies constitute the most obvious and significant component of this category (Burrows, 1996). Such information gathering and processing agencies make extensive use of commercially available data acquisition systems and derived products. Private information gathering and investigation services are another component of this application category. Information and intelligence users often require data of fine temporal and / or spatial resolution.

19) Public Heath

The *Public Health* application category includes all users, both public and private, concerned with the protection and preservation of human health. Specific applications include the detection and prediction of vector-borne disease outbreaks, agricultural monitoring for early-warning of famine, targeting of nutrient rich runoffs for testing of toxic dinoflagellates, targeting of chemicals to control Aedes mosquitoes in the fight against dengue, location of continual forest canopy corridors for transportation of yellow fever through monkey populations, and the detection of parasite habitat for ticks, trematodes (*schistosomiasis*), and tsetse flies (Barinaga, 1993; Beck et al., 1994; Epstein et al., 1993; Hay et al., 1997; Hugh-Jones, 1989; Pope et al., 1994; Wood et al., 1992).

20) Media, Press, and Education

The *Media, Press, and Education* application category includes public and private parties utilizing imagery from remote sensing data acquisition systems to produce visually appealing pictures, maps, and graphics for public presentation, entertainment, art, and journalism. Specific applications include the use of digital elevation models (DEM), as well as imagery for video games, weather news graphics, and for material in educational textbooks. In K-12, remote sensing imagery is being introduced in a variety of textbooks, and at post secondary and graduate schools, course level applications are central. SPOT data was used in 1988 by NBC News correspondent Fred Francis for his story on chemical weapons production in Rabta, Libya. TM images of the April 29, 1986 nuclear reactor incident in Chernobyl not only provided the world with the first views of the damage, but it was also argued by some experts that the use of space imaging forced the Soviet Union to change its policy on what to acknowledge to the world community about the incident (McDonald, 1989).

To identify the European and Asian application thrusts, a 3-part methodology was developed. The three components included 1) a literature review, 2) surveys, and 3) personal interviews. The literature review process involved an exhaustive review of peer-reviewed journal literature from 1995-present. Both keyword searches of library databases and searches of all volumes of specific geo-spatial science journals were inspected for pertinent satellite remote sensing applications literature. The references were then imported into an Endnote database for further analysis and generation of an annotated database. To derive quantitative statistics, fields including application category, data acquisition system, geographic region, and authors affiliated institution or organization were included. Additionally, the database will allow for each specific application reference to be classified with respect to where it lays in the research to operations continuum. To accomplish this we have defined each reference as either an applied science, application demonstration, or an operational application.

The survey component is utilized to validate the results of the literature review rankings. Graphics were developed to depict each of the twenty applications categories priority for Europe and Asia. International scientific meetings in both regions were used as a forum to present the results to officials and colleagues from government agencies, private firms, and academic institutions. The officials were asked to either agree or disagree with each applications ranking, and to critically critique the research and give additional insight. The survey results were also used to identify specific applications that may have been excluded from the study and to adjust the rankings if clearly necessary.

The third component of the international applications research involved personal interviews with scientists, business people, and government officials from Europe and Asia. The interview process was not as concerned with the results of the applications rankings as it was with the general knowledge of the interviewee. The interviewees were asked to share their opinion about the potential of each application category for their region. They were also asked to identify specific applications that they felt were high priority, and to give insight into the reasons why various applications may or may not have developed. Our goal was to further understand the specific needs that each region required with respect to data and applications.

The current status of this research project is as follows. The literature review has been completed with nearly 300 references of applications research entered into Endnote software for statistical analysis. Trips to Europe and Asia (refer to list of meetings / conferences below) have allowed for an extensive survey/interview process for which the results are currently being analyzed. Cooperation between the RSRU and NASA's Commercial Remote Sensing Program (CRSP) has recently been initiated. Various CRSP personnel have critiqued our initial results, and have given valuable input as to the form the results should be presented to decision makers for the greatest utility. Figure 2.1.4(b) summarizes the results from the literature survey and the interview survey and ranks each of the twenty international applications areas as potential users of remote sensing technology.

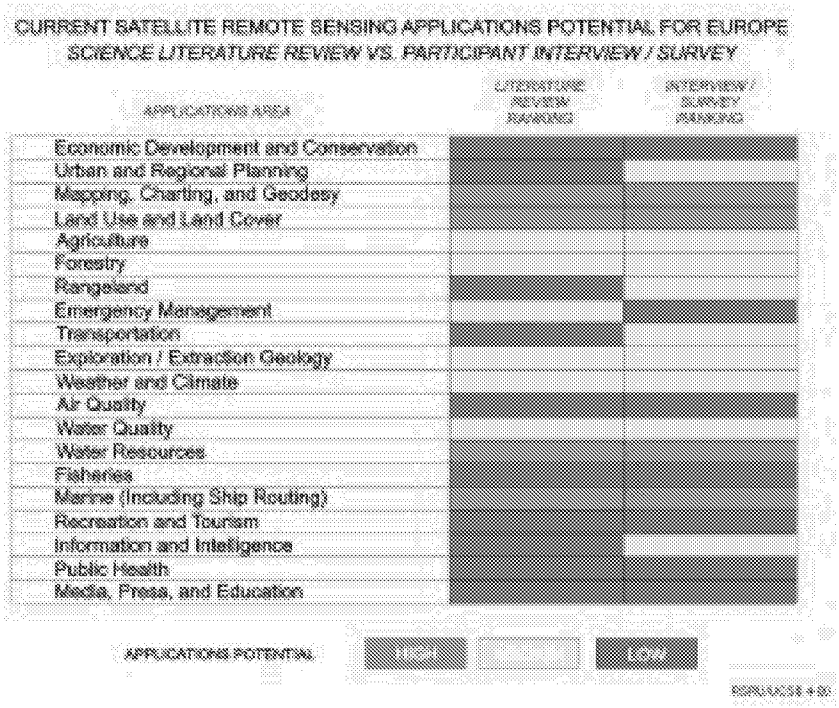


Figure 2.1.4(b). Summary of international applications of remote sensing technology.

The principal meetings and conferences attended during this reporting period were:

- 28th International Symposium on Remote Sensing of the Environment, March 27th – 31st, 2000, Cape Town, South Africa. "Information for Sustainable Development". The ISRSE meeting was an excellent chance to meet with foreign officials to discuss international remote sensing applications thrusts. In addition to meeting with delegates at the conference, we toured the South African CSIR Space Applications Center in Magaliesburg, which proved to be invaluable with respect to understanding the needs the geospatial data needs for developing nations.

- 19th Meeting of the International Society for Photogrammetry and Remote Sensing, July 16th – 23rd, 2000, Amsterdam, The Netherlands. "Geoinformation for All". Delegates from various research, commercial, and university affiliations aided with the validation of our literature review, as well as answer some direct questions about the socioeconomic and political factors that may have been contributing to the results that we were finding.

- John C. Stennis Space Center Commercial Remote Sensing Program, June 28th – 30th, 2000, Mississippi. Various personnel from the CSRP met and discussed with us their needs with regard to understanding the nature of international applications. The goals of our research were presented and critically reviewed. A cooperative relationship was established, and will be utilized where appropriate.

2.1.5. Mezzetti and Associates - Initial Identification of Baseline Issues for the Commercial Sector

During this reporting period Mazzetti and Associates continued to work with ISRG researchers on the identification of baseline issues impacting commercial sector involvement in remote sensing applications. The material that follows represents an overall summary discussions and knowledge accumulation concerning challenge facing the private sector entities as they seek to develop operational remote sensing applications. The

material presented herein is still in a preliminary form. As such it is only a starting point, from which NASA HQ can hopefully gain a better appreciation of key challenges in this area and coordinate more closely with the commercial and public sectors to assure mutual success. Mazzetti and Associates and ISRG researchers have made the following overall observations; these are preliminary and should be quantified through a methodical approach and the recommendations verified.

NASA's applications, outreach and education task is multi-fold:

- Maximize the return on U.S. taxpayer investment in ESE and provide public service through the unique NASA function;
- Nurture and assist healthy and robust U.S. remote sensing and value added commercial sector growth;
- Simultaneously support the inherent government functions of other federal, state and local agencies (such as Natural disaster prevention, response and mitigation, national and state economic projections, etc.); and,
- Maintain a level playing field among these and other stakeholders, while promoting competition and efficiencies in the applications system.

To assure mutual success, and accomplish its objectives, NASA HQ through Code YO should develop an improved understanding of how they can serve the taxpayer, other government agencies, and the commercial data and information user sector, and how they can most effectively partner with the commercial data and information supplier sector.

Challenges to Development of U.S. Commercial Remote Sensing/ Value Added Industry, among others, include:

Historical, currently known and potential commercial data providers and value added suppliers.

- Access to data
- Access to capitol to develop constellations of satellites capable of supporting operational applications
- Market understanding and marketing capacity
- User cultural obstacles, including influence of past negative NASA applications experiences (AgriStars, Landsat)
- Cost/benefit analysis by users (e.g., is there a "value" added to the current method of performing end user tasks, reaching end user goals? Compared with the ramp up costs in acquiring capacity?) (see below)
- Inadequate levels of fundamental research in key area impacting applications (e.g. classification, registration, data fusion, and visualization)
- Inadequacy of current process of moving from fundamental research to operational implementation.
- Traditional start-up and small business issues (technology versus business acumen, controlled versus explosive business growth, etc.) Limited workforce trained in remote sensing or cross-trained in applications areas. Workforce education in post-secondary education, and mid-career training is also limited.

Possible Market Challenges to be Overcome in Federal, State & Local Government Use of Remote Sensing Data / Value-Added Products and Services

- Very real risk of relying on advanced technology with no assurance of long term data/information continuity.
- Access to data/information
- Funds to purchase value added products and services at competitive market prices.
- Computer hardware, antenna, software equipment (Internet access influence?)
- Complexity of data/information processing.
- Lack of awareness/experience in implementation of operational applications of satellite remotely sensed data.

- Understanding of complexity of remote sensing/GIS integration issues.
- Cultural obstacles in the user agencies.
- Cultural obstacles in the data provider agencies/organizations.
- Cost/benefit analysis by user agency (e.g., is there a greater "value" added to the current method of performing end user tasks, or reaching end user goals by using this data?).
- Limited workforce trained in remote sensing or cross-trained in applications areas. Workforce education in post-secondary education, and mid-career training is also limited.

Monetary Costs to Public User Agencies:

- Personnel
- Personnel training
- Capitol costs to develop internal remote sensing processing capacity (i.e. Hardware and software)
- Data access.
- Data/information costs.
- Appropriation of and agency budgeting of funds to purchase data services.
- Costs to purchase of external value added products and services.
- Operational data processing.
- Storage retrieval and long term data archiving costs.
- Personnel training (oversight and interpretation)

Observations - Workforce Issues, Cross-Disciplinary Training And Establishing A U.S. Earth System Science And Remote Sensing Professional Career Infrastructure

Attitudes toward hiring remote sensing and value-added contractors vary by sector, company, agency division, and sometimes by key individuals within specific organizations. NASA should methodically document government personnel attitudes about hiring remote sensing data providers and value-added contractors. Commercial remote sensing and value-added industry capacities and limitations must be understood well enough to mitigate significant risk to user agencies and organizations, and too NASA from partnering in a highly visible field. Impacts of regional climate change on the public at large, on key U.S. economic sectors, and user information needs also must be better understood.

Anecdotal attitudes of two climate dependent corporations' data and information staff are described later in this report, and summarized here:

Users rely on several data and analytical sources simultaneously. A commercial product is only one part of the necessary mix to assure end user accuracy and reliability;
Contractor reliability is situational, depending on the particular individuals on duty and their availability;
Each end user who relies on outside work takes painstaking measures to double and sometimes triple check accuracy and quality; and,
Even with ample funds to purchase outside products, in a high-stakes environment, end user staff prefers to rely on their own independent analytical products, using outside sources only where excellence prevails.

Workforce supply is widely recognized as a major market barrier to increasing growth in the commercial remote sensing industry. However, the commercial remote sensing industries growth attempts are already negatively impacting existing the workforce. In several discussions, "cannibalization" of state and federal agency personnel to staff the nascent U.S. commercial remote sensing industry was reliably reported. One reported case involved a commercial company aggressively recruiting from state government agencies nationwide, allegedly promising full college scholarships for the children of recruits if they came to work for the company.

Remote sensing expertise within federal, state and local government agencies must be maintained and enhanced. At a minimum, civil servants must be able to competently evaluate and oversee their outside commercial contractors, reliably articulate results of outside contractor work to higher level government agency officials, and justify or mediate additional budget expenditures. Maximizing taxpayer benefit from the ESE

investment probably requires a stronger and more direct NASA and federal government investment in building an applied science and applications infrastructure.

Three principal approaches should be considered as applied science and applications strategies are designed. These are:

1. NASA and other federal agencies aggressively nurture an Earth system science knowledge transfer infrastructure in the United States and abroad that could be executed by a public and private sector workforce. This would include a workforce skilled in remote sensing applications as a threshold where necessary (e.g. for states and sectors disinterested in applied climate science).

2. NASA should investigate the feasibility of placing cross- trained and multi-disciplinary scientists (e.g. meteorologists and climatologists cross-trained in business, medicine or public policy) into industry, and in state, local and federal government agencies in order to factor predictable Earth system changes into economic and societal planning. NASA and other Federal Agencies could expedite this objective by developing the necessary college and university programs and partnerships with the public sector and private industry to train the coming workforce.

3. Applications -- NASA headquarters should assess existing undergraduate and graduate degree programs (including curriculum), and mid-career retraining programs directed at the remote sensing and applications workforce. The study should measure whether existing programs are sufficient to meet currently anticipated workforce needs for remote sensing in the data provider and user sectors for the next 20 years. It should recommend various ways to address the challenges discussed herein.

Each of these studies should address workforce issues on a national scale, taking into account the needs of key potential users and information suppliers (as defined in the ACE strategy), and should include the domestic and export markets. They also should recommend ways and means to meet future workforce needs, including timeframes.

During the course of this work ISRG researchers were informed that NASA was re-evaluating it's relationship with Mazzetti and Associates and would prefer to fund their activities in a more direct fashion. As a result of discussions among participants, it has been decided that any future work in this area come through funding directly from Code YO to Mazzetti and Associates. ISRG has is proud of the cooperative work that has been undertaken to date with the dedicated team at Mazzetti and Associates and will work with this group in the future as tasks and funding opportunities arise.

2.2. Information Science Research

2.2.1. Global Data Set Thematic Accuracy Analysis

Thematic accuracy of the IGBP Global 1-km Land Cover Data Set (v.1.0 IGBP-DIScover) was statistically assessed. The DISCover data set was prepared from 1-km AVHRR composited NDVI data. This data set arises from the mandate of the IGBP-DIS to provide accurate, fine-resolution land cover data for use by IGBP Core Projects. The data set recognizes 17 types of land covers with a list of units developed in concert with and approved by the Core Projects. This research was principally funded under a separate National Aeronautics and Space Administration Grant (NAG5-6259) through the Land Cover and Land Use Change Program. However, support under the ISRG Grant was crucial to the conduct and completion of this research and a brief summary of the results of this work is included in the following material.

Accuracy of the DISCover 1.0 product was assessed by a core sample of approximately 379 primary (or "core") samples in a procedure that yields confidence limits on the accuracy of classification as well as on specific probabilities of misclassification. In addition, the core sample were expanded into "confidence sites": larger regions around each sample center that were used for fine resolution land cover mapping as specified in the IGBP-DIS protocol. These confidence sites will also form the vanguard of an ongoing global network of test

sites for accuracy assessment of successive land cover maps by the IGBP and the global land cover community at large.

This research directly addressed the primary LCLUC goal of developing the capability to perform global inventories of land cover and land use from space, a process in which accuracy assessment is a critical part. It also directly addressed the call for development of techniques and methods for applying satellite data to land use and land cover problems.

Issues of data set sampling design, image geometry and registration, and core sample interpretation procedures are addressed. Landsat Thematic Mapper and SPOT satellite image data were used to verify 379 primary core samples selected from DISCover 1.0 using a stratified random sampling procedure. The goal was to verify a minimum of 25 samples per DISCover class; this was accomplished for 13 of the 15 verified classes. Three regional Expert Image Interpreters independently verified each sample and a majority decision rule was used to determine sample accuracy.

For the 15 DISCover classes validated, the average class accuracy was 59.4% with accuracies for the 15 verified DISCover classes ranging between 40.0% and 100%. The overall area weighted accuracy of the data set was determined to be 66.9%. When only samples which had a majority interpretation for errors as well as for correct classification were considered, the average class accuracy of the data set was calculated to be 73.5%.

The majority of this research was completed during the previous reporting period under this grant. Authorship and editing of the journal articles describing this work, however, were not completed in time for inclusion in the previous ISRG Progress Report and Proposal. They were, however, included in our last progress report and proposal to give NASA a complete summary of our work on this topic.

The research performed under this grant was described in detail in a Special Edition of the journal *Photogrammetric Engineering and Remote Sensing* (September, 1999). The following articles in this journal summarize research that was directly supported under this NASA Research Grant:

- *The IGBP-DIS Global 1-Km Land-Cover Data Set: A Project Overview*
  (Alan S. Belward, John E. Estes, and Karen D. Kline)

- Landsat Thematic Mapper Registration Accuracy and its Effects on the IGBP Validation
  (Gregory J. Husak, Brian C. Hadley, and Kenneth C. McGwire)

- Image Interpretation Keys fo rValidation of Global Land-Cover Data Sets
  (Melissa Kelly, John E. Estes and Kevin A. Knight)

- *Thematic Validation of High Resolution Global Land Cover Data Sets*
  (Joseph Scepan)

- *The DISCover Validation Image Interpretation Process*
  (Joseph Scepan, Gunter Menz, and Matthew C. Hansen)

- *The Way Forward*
  (John E. Estes, Alan Belward, Thomas Loveland, Joseph Scepan, Alan Strahler, John Townshend, and Chris Justice)

2.2.1.1. Space Station Imagery for Validation of Land Cover Data Sets

The International Space Station (ISS) will provide a multi-use platform for numerous space science, Earth observing and outward viewing applications. The ISS will house a multipurpose research facility that will have a permanent crew, enabling continuous maintenance and care of instruments. ISS is intended to support basic and applied research endeavors in chemistry, physics, and biology. It will be an exceptional platform for conducting remote sensing of the Earth, astrophysics, and space physics research programs. ISS will also operate as a testbed for engineering studies and complex technological developments.

Sixteen nations are participating in the International Space Station Program. Nations designated as Partner States are those who are signatories to the 1998 Intergovernmental Agreement. Partner States are the United States, Canada, Japan, Russia and 11 European nations: Belgium, Denmark, Germany, France, the Netherlands, Norway, Sweden, Spain, Switzerland, and the United Kingdom. Italy and Brazil are contributors as well, through bilateral agreements with NASA. The 16 countries are not only combining forces on the manufacture of the ISS, but also on its use. Within many of the research disciplines, international collaborative working groups are constructing research plans that share research equipment, consequently preventing unnecessary duplication and optimizing research return.

The potentials for sensors on this craft are enormous in terms of remotely sensing the Earth's atmosphere, land and seas. Its multipurpose uses allow not only Earth-viewing activities but also space viewing research such as documenting astrobiology, meteor activities, supernovas, and local solar system occurrences.

This research focuses on the Window Observational Research Facility (WORF), located in the United States laboratory module. The WORF is an earth-observing window that allows for the transmission of visible to near infrared portions of the electromagnetic spectrum. The WORF can take advantage of a variety of payload opportunities, involving both astronaut-operated and autonomous operations, covering a number of different Earth observations missions, including:

- Observations of ephemeral events and natural disasters, such as floods, volcanic eruptions
- Documentation of changes in the terrestrial landscape, such as deltaic changes due to excess sediment availability due to de-forestation
- Validation of land cover investigations
- Observations of man-made atmospheric events, such as the production of large scale SO_2 clouds in urban areas
- Documentation of ocean color changes and other macro scale-changes in deep ocean surface
- Investigation/validation of new sensor technology

Currently, the instruments scheduled to be mounted on the WORF instrument rack assembly include a complement of cameras, including Nikon F5 35mm, and Nikon electronic still camera, with a variety of lenses which have up to 400 mm telephoto.

This component of ISRG research focuses on utilizing photographs taken be astronauts from Space Shuttle missions, and establishing whether these astronaut acquired photographs can be used to aid in land cover map validation. ISS cameras are spectrally and spatially similar to the cameras used on space shuttle missions. This research to determine the role of astronaut-acquired photography from shuttle in validating past and current land cover maps is essential to establishing a successful methodology for the cameras which will be taken aboard ISS. These types of camera systems have never been quantitatively assessed for this application before. When completed, this study will establish a baseline for researchers who are utilizing these systems.

The focus of this research is validation of land cover data sets and this research directly furthers the IGBP validation effort, concluded this year. For the shuttle validation effort, this study reviews the methods developed for validating an Advanced Very High Resolution Radiometer (AVHRR)-based global land cover map, with astronaut acquired photography. For comparison, we will also be utilizing Landsat Thematic Mapper (TM) imagery. The land cover data set used in this study is an AVHRR-based global land cover data set produced by researchers at the U.S. Geological Survey (USGS) and Earth Resources Observation Systems (EROS) Data Center (EDC). The North America land cover data base is one portion of a global land cover characteristics data base that is being developed on a continent-by-continent basis. All continents in the global data base share the same map projections (Interrupted Goode Homolosine and Lambert Azimuthal Equal Area), have 1-km nominal spatial resolution, and are based on 1-km AVHRR data spanning April 1992 through March 1993. Each continental data base has unique elements that are based on the salient geographic aspects of the specific continent. In addition, a core set of derived thematic maps produced through the aggregation of seasonal land cover regions is included in each continental data base. These are:

- Global Ecosystems (Olson, 1994a, 1994b)
- IGBP Land Cover Classification (Belward, 1996)

- U.S. Geological Survey Land Use/Land Cover System (Anderson et al., 1976)
- Simple Biosphere Model (Sellers et al., 1986)
- Simple Biosphere 2 Model (Sellers et al., 1996)
- Biosphere-Atmosphere Transfer Scheme (Dickinson et al, 1986)

The three derived land cover thematic maps which are used in this specific research are U.S. Geological Survey Land Use/Land Cover System (Anderson et al, 1976), Global Ecosystems, and IGBP Land Cover Classification (Belward, 1996). These three data sets each have a specific number of land cover classes associated with them: the U.S. Geological Survey Land Use/Land Cover System (modified level 2) has 24, Global Ecosystems has 94, and the IGBP Land Cover Classification has 17 different land cover classes.

The methods involved are based on testing three different land cover classification systems in order to determine:

1. Which data set provides the highest overall accuracy;
2. Which is best validated using astronaut acquired data; and
3. Which land cover classes lend themselves to validation with astronaut photography.

Five vegetation classes have been identified as most suitable for validation with Shuttle imagery. These are:

1. Evergreen needleaf forest
2. Savanna
3. Cropland/vegetation mosaic
4. Grassland
5. Shrubland.

These classes are being assessed within each classification system by a rigorous comparison of individual class legends for likeness and a statistical summary of the accuracies of the individual classes in each legend. A confusion matrix is being developed to aid in understanding correctly mapped portions of each selected classes as well as errors of omission and commission. A second statistical test, an adaptation from the Kappa statistic, will also be utilized to assess the error and accuracy of Shuttle imagery potential. This study tests the capability of astronaut-acquired photography to document and validate land cover maps and land cover change over time.

Initial analyses indicate that validation results among the three maps using Shuttle Photography are similar. The exception to this is those randomly generated test points that fell on two or more land cover classes which border each other. In this situation it appears that validation is aided by utilizing other resources such as Astronaut Acquired Photography as well and Landsat TM imagery. However, at times it appears that the more detailed the classification system, Olson's for example, the higher likelihood there exists for there to be differences in bordering land cover classes between Olson's differentiation and IGBP or Anderson's class distinctions. The statistical analysis of this research is still in progress and will be completed and published by the end of 2000.

2.2.1.2. Spatial / Geometric Analysis of Validation Data Sets

Research showing the spatial offset of Thematic Mapper (TM) data was completed during the previous funding period. The results of this research showed a spatial bias in the basic processing of TM data products. The research also assessed the impacts of this offset on the IGBP validation exercise.

This study showed that a geographic offset exists in systematically corrected National Landsat Archive Production System (NLAPS) data for the conterminous United States. This discovery was proven by comparing the NLAPS data with precision registered Multi-Resolution Land Characteristics (MRLC) data from identical locations as the NLAPS scenes. NLAPS data has an average offset of nearly one kilometer in both the eastern and southern directions. Vectors showing the offset at checked points are shown in Figure 2.2.1.2(a). It is important to note that the scale of the vectors are not drawn to the scale of the map, but have been exaggerated for viewing purposes.

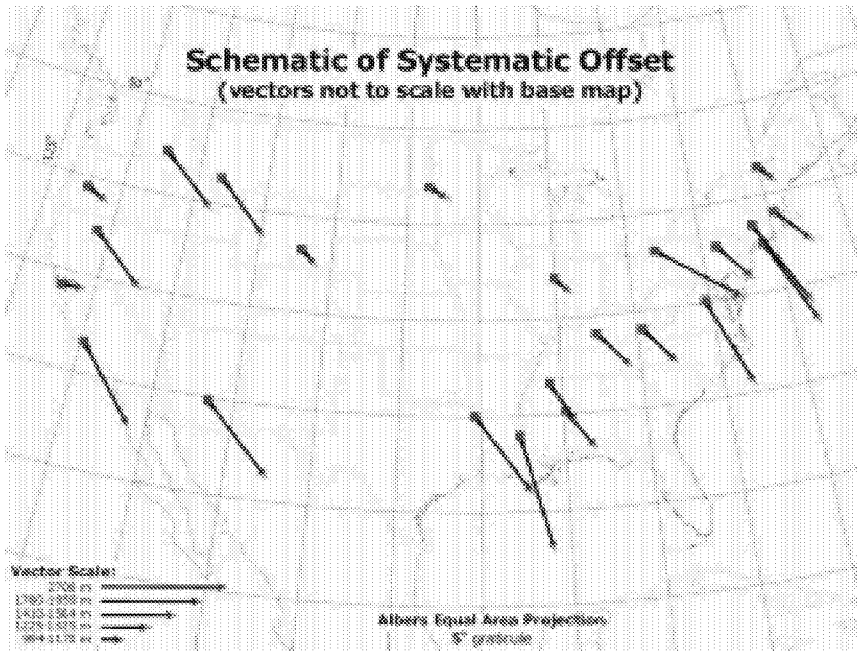


Figure 2.2.1.2(a). Schematic view of recorded geographic offsets at points in the Conterminous United States.

In addition to the discovery of the offset, an attempt was made at determining how such an offset may affect the DISCover validation exercise. One method for determining the effect on the validation, in general terms, was to compare pixels on the DISCover map with the corresponding pixels of an identical version of the landcover map that has been offset by the average bias found in this study. The results of this test should indicate how much of a problem the given offset would be for the validation. In this study it was revealed that nearly 80% of the pixels in the conterminous United States would be unaffected as a result of this offset.

Finally, this study attempted to apply the results achieved to gain an improved understanding of how this bias may account for the DISCover accuracy statistics found as a result of the validation. Limitations of this study include factors such as study area, the number of selected samples that were tested, and errors in the creation of the DISCover data. Broad questions relating to the application of this study were addressed to focus the usefulness of the results and highlight inappropriate application of this study (Husak *et al.*,1999; Husak, 1999).

2.2.2. Updating the Status of Global Thematic Map Information

RSRU personnel continue to participate in the activities of the International Steering Committee for Global Mapping (ISCGM), as well as the GSDI and Digital Earth organizations. Within the ISCGM, the data policy is a continuing critical component with the release of Global Map version 1.0. RSRU personnel have continued to actively participate in the development of this policy, which will culminate in the finalization of the data policy for Global Map future versions. RSRU

Our work with the ISCGM continues. Following the highly successful Global Mapping Forum in November 2000, Dr. Estes was asked to give the keynote address at the 7th United Nations Regional Cartographic Conference (UNRCC) for the Americas in New York in January 2001. While he was unable to attend the conference, his materials were provided to Dr. John Kelmelis of the U.S. Geological Survey for presentation. In addition to the UNRCC meeting, presentations about Global Map have also been given at the Hiroshima Institute of Technology Workshop on Advanced Remote Sensing in Hiroshima, Japan, March 2001. Ms. Kline participated in both the GSDI and ISCGM meetings in Cartagena, Colombia, in May 2001. She is also a member of the Steering Committee for the GSDI and the Assistant Secretary General of the ISCGM. We are receiving partial support for work in this area from the National Mapping Division of the U.S. Geological Survey.

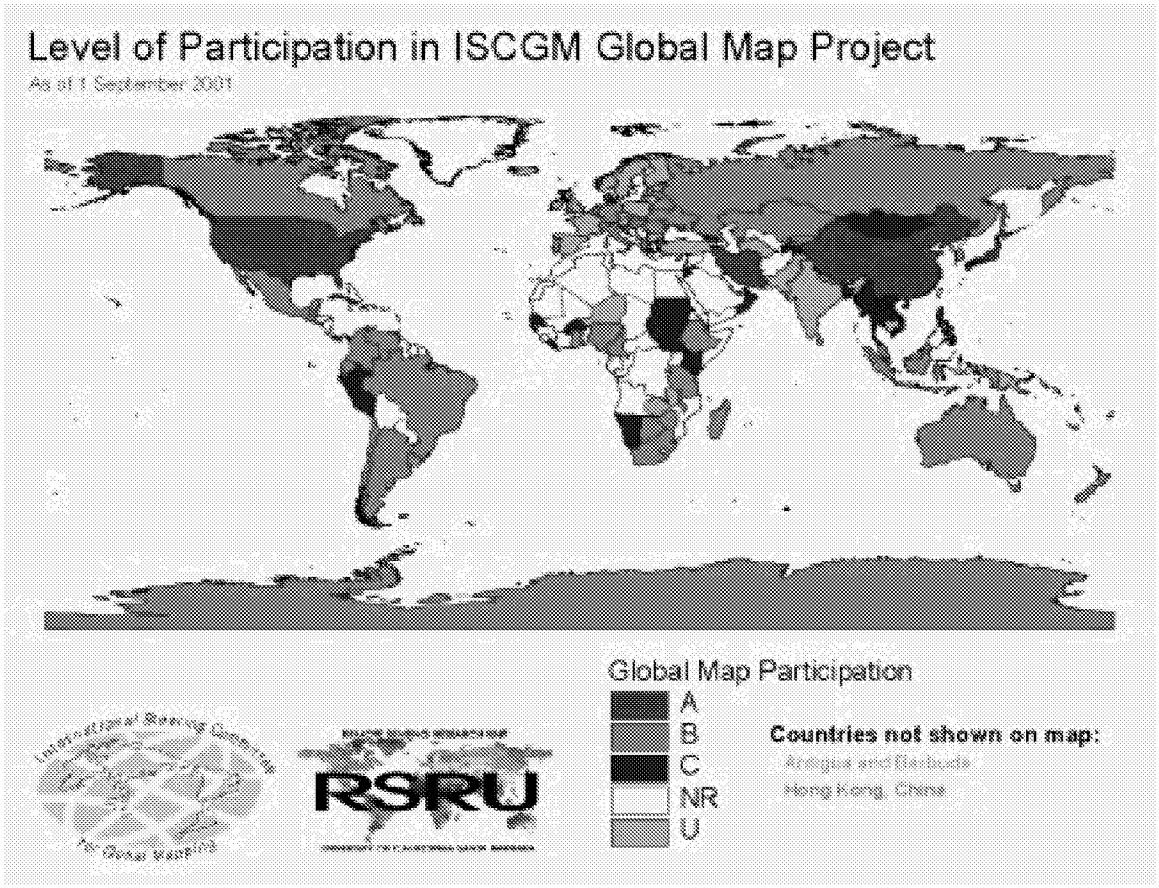


Figure 2.2.2(a): Participation in the Global Map Project

In addition to providing a forum for the exchange of information among NMAs, ISCGM is coordinating the upgrading of small-scale globally consistent data sets. ISCGM's goals are to promote cooperation and collaboration among NMAs for the development and dissemination of improved products that can support a variety of users from public policy decision makers to resource planners and environmental managers. Professor Estes and ISRG/RSRU personnel have been working with ISCGM members and the Secretariat on an action plan and specifications for the global map product, and the determination of the current status of global map coverage. In addition, in preparation for the release of Version 1.0, discussion on the data policy has been initiated, and RSRU personnel are playing a vital role in its evolution.

The major focus of our grant activity with the ISCGM, at this time, is the creation of Global Map; and ensuring that this activity is closely coordinated with the NASA led Digital Earth effort. We continue to believe that there are real synergistic opportunities between these projects and that there is considerable room for expansion of coordination and mutually beneficial collaborative efforts. A portion of our work in this year has been devoted to forging closer ties among Digital Earth, ISCGM and the Global Spatial Data Infrastructure (GSDI) activity.

As defined by ISCGM, a "global map" is a data set consisting of several core data layers and meets the following requirements:

- Covers the entire surface of the earth;
- Meets consistent specifications for the entire planet;
- Many people can access these data; and
- Must be updated regularly.

The core data layers of the Global Map version 1.0 product are: administrative boundaries, land use, vegetation, drainage systems, elevation, and transportation networks - see Figure 2.2.2(b). The base data product will consist of data from various pre-existing global data sets, identified and described below.

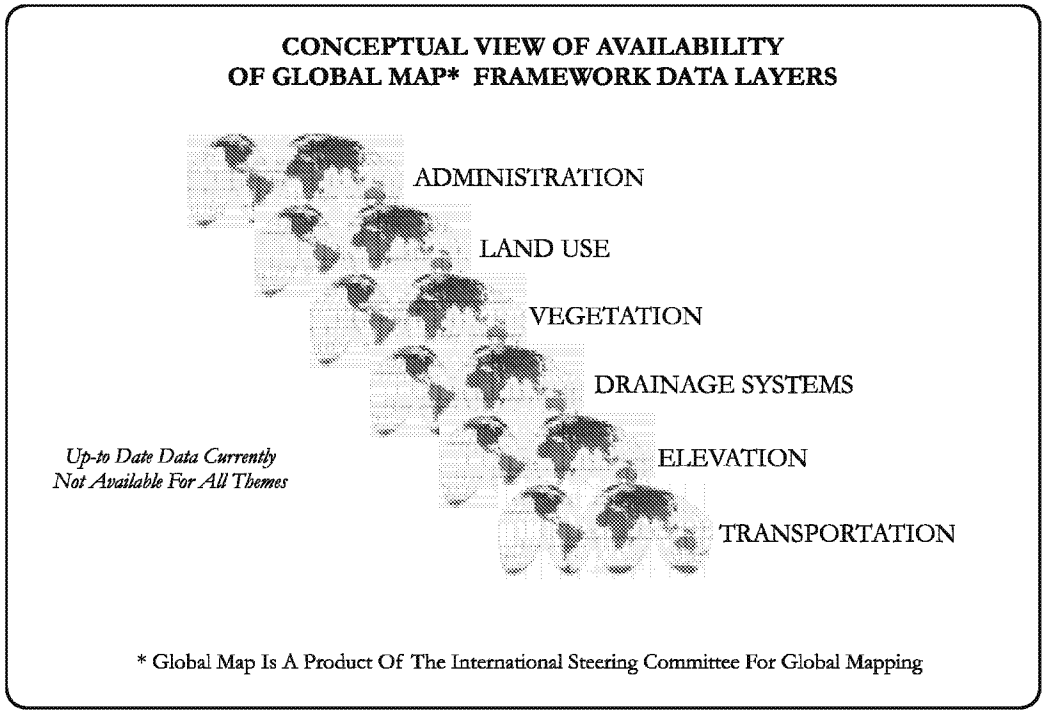


Figure 2.2.2(b): Global Map Framework Data Layers

Vector Map Level 0 was formerly the Digital Chart of the World, and is produced by the U.S. National Imagery and Mapping Agency. It is a global database that includes roads, railroads, rivers, lakes, streams, major utility networks, cross-country pipelines, communication lines, airports, elevation, coastlines, international boundaries, populated places, and geographic names. The data are from the Operational Navigation Charts and the Jet Navigation Charts. This product is available for $200.00 US. VMap0 will provide the administrative boundaries, drainage systems, and transportation network layers.

GTOPO30 is a global 30-arc second digital elevation data set. It is produced by the USGS' EROS Data Center and is available from EDC either over the Internet, CD-ROM, or 8 mm tape. The data are from the Digital Chart of the World and other previously existing elevation data. GTOPO30 will be the elevation data layer of Global Map.

The IGBP DISCover land cover characteristics database was derived from a yearlong series of AVHRR NDVI composites. There are 17 different land cover classes in the IGBP legend. This data is available from the EROS Data Center web site. The land cover (vegetation) layer will come from the IGBP DISCover data set (Loveland and Belward, 1997; Belward et al., 1999).

These globally consistent thematic data sets are important for a variety of reasons. First of all, sustainable development researchers have a need for global data sets that adhere to "global map" specifications. Consistent and accurate data sets will have far reaching benefits for the sustainable development research community, as well as others. By having a regularly updated database containing a number of important layers or themes, it will be easier to track changes on the earth's surface, and to determine whether or not development is sustainable. The global modeling community will also benefit from having a globally consistent database. This will allow them to model various regions of the earth's surface and make comparisons between

regions, as well as to create global models. By making the data widely accessible and easily available to everyone everywhere, environmental resource managers and planners can quickly and more accurately keep track of the resources for which they are responsible. Following is a brief description of the recent activities involved in the creation and promotion of the global map.

From November 13 to 16, 1996, the "Interregional Seminar on Global Mapping for the Implementation of Multinational Environmental Agreements" was held in Santa Barbara, California. This meeting was organized by ISRG personnel and was cosponsored by the Remote Sensing Research Unit, University of California; the Geographical Survey Institute, Ministry of Construction, Government of Japan; and the Department for Development and Management Support Services, United Nations. There were sixty-five participants representing over twenty different countries, ranging from small island states to continent wide nations. U.S. government agencies and international non-governmental organizations were also represented. ISRG personnel provided the support and rapporteur services. The main topic of the Seminar was the "global map". The key issues mentioned above were discussed, with the result being the "Santa Barbara Statement," which is included as part of the Report and the Proceedings of the Seminar (Estes et al., 1997). The United States and Japan have jointly submitted the "Santa Barbara Statement" to the United Nations General Assembly as input to Agenda 21, the action program adopted at the 1992 United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro.

In November 1997, the "Global Mapping Forum '97" was held under the auspices of the International Steering Committee for Global Mapping (ISCGM) in Gifu, Japan. The primary purpose of ISCGM is to examine measures that concerned national, regional and international organizations can take to foster the development of Global Mapping. Essentially, mapping that can facilitate the implementation of global agreements and conventions for environmental protection as well as the mitigation of natural disasters and encourage economic growth within the context of sustainable development. This Committee is made up of the heads of 14 national mapping organizations and representatives from international agencies, academia, and industry.

Subsequent meetings of the ISCGM have been held in Sioux Falls, South Dakota, June 1998, in conjunction with the Global Mapping Forum. In 1998, in conjunction with the 3rd Global Spatial Data Infrastructures symposium, an ISCGM meeting was held in Canberra, Australia. In July 1999, at the Cambridge Conference, a meeting of national mapping agencies, the 6th ISCGM meeting was held. By holding the ISCGM meetings in conjunction with other symposia, it enables participants, including RSRU personnel, to link together the various projects, such as Digital Earth, GSDI.

Cape Town, South Africa, was the site of the 7th meeting of the ISCGM, in conjunction with the 4th Global Spatial Data Infrastructures "Engaging Emerging Economies" symposium. At this meeting, RSRU personnel presented a paper entitled, "Synergy -- The Importance of Relationships." The main focus of this paper was the point that together, these three complementary efforts (Global Map, GSDI, and Digital Earth) provide the three most critical components: the technology, the standards, and the data. Relationships between Global Map, GSDI, and Digital Earth are critical to the continued evolution of the three, for without each other, the reason for their existence disappears (Kline et al., 2000).

In addition to participation at GSDI and ISCGM meetings, a special session related to Global Map and related issues was organized for the 28th International Symposium on Remote Sensing of Environment, also held in Cape Town, South Africa, in March 2000. Prof. Estes presented a paper entitled, "Strategic Planning for Global Mapping." Also at this session, the Vice Chair of ISCGM, Mr. Peter Holland of AUSLIG, Australia, presented a paper detailing the history and goals of the ISCGM. When combined with the presentation by Dr. Timothy Foresman on Digital Earth, it provided a forum to introduce the concepts to other interested organizations.

Prof. Estes presented an invited paper on the Global Map project at the 15th United Nations Regional Cartographic Conference for Asia and the Pacific. This meeting was held in Kuala Lumpur, Malaysia, in April 2000. Representatives from more than 40 countries attended. Several nations agreed, in principle, to participate in the Global Map project at this meeting.

At the Annual ASPRS meeting, held in Washington, DC, in May 2000, RSRU personnel presented papers related to Global Map. Prof. Estes presented "Global Mapping: Remote Sensing's Challenge," while Ms. Kline

presented "Political and Administrative Challenges for Global Mapping." The paper presented on the challenges for global mapping is a direct result of Ms. Kline's Master's thesis, History of Global Mapping: Lessons, Issues and Challenges for National Mapping Organizations. This work is in answer to a question posed last year: "Are there technological, institutional, and economic barriers to the creation of a global map? At this time, we surmise that there are no technological barriers, but that there do exist institutional barriers."

The main premise of this thesis is that national mapping agencies, as the keepers of detailed national inventories, play a key role in the development of these data, standards, and technology development efforts. However, they are plagued by a number of problems, some of which are more easily overcome than others and some of which are currently being resolved. These problems (administrative, political, general, and technical) are summarized below (Kline, 2000).

Collaboration and cooperation between national mapping agencies (NMAs) and international non-governmental organizations (NGOs) is important in the creation of global geospatial data sets, such as Global Map. By having these various organizations involved, the cost of creating the data set can be shared and no one organization may need to bear the burden of full expense. In addition, the many organizations and countries involved have a voice in the effort; and they gain some measure of credibility for their participation by having others involved. Basically, no one wants to be left out. But with such collaboration and cooperation, difficulties and problems arise owing to the number of organizations involved and their different charters or remits, and agendas, political or otherwise. "However, international collaboration is also needed for high-quality development and application of global databases" (Hastings et al., 1991).

The main factors inhibiting development and/or use of global data sets can be subdivided in many ways; for the purpose of this discussion, as stated before, these have been broken down into administrative/institutional, political, practical, and technical categories. Administrative/institutional focuses upon the various administrative or institutional factors that affect the development of global geospatial types of data sets. The political category contains those political factors that are related to the various political agendas and definitions of each of the organizations involved. Those factors that are considered to be general assumptions, such as lack of knowledge of existence, have been placed in the practical category. The technical category covers those issues related to infrastructure and technology that are required to create and/or use these data. Different issues may fall in one or more categories. It is important to note that this list is not complete, and a wide variety of hard to categorize problems can and do arise on a continual basis. The following material expands upon these issues in the following order: administrative, political, practical, and technical.

Administrative challenges include economics (without funding, there is no data set development), relationships between and within organizations are vital, variety of data licensing policies, and confusion caused by different definitions for the same terms. Political support is often vital for the life of a data development project, for oftentimes, without political support, there is no funding. Political challenges also include the fact that these types of data are often considered relevant to national security. And different political viewpoints towards data policy (i.e., U.S. viewpoint (COFUR) vs. U.K. viewpoint) can create difficulties when different countries are working together. Practical challenges that must be overcome include:

- Lack of knowledge that the data exist;
- Lack of knowledge of the quality of the data;
- Lack of education or capacity building;
- Lack of commitment by decision makers;
- Lack of metadata;
- Copyright issues;
- Analog/legacy data often incompatible with digital data;
- Perceived incompatibility between national/regional level efforts with global efforts;
- Isolation of efforts;
- And the need to make global issues locally relevant, and local issues globally relevant.

The technical challenges that exist include:

- Lack of appropriate infrastructure;
- Need for archiving and data storage;

- Tool capacity (having the appropriate tools at hand);
- Distribution and dissemination mechanisms in place; and
- Need for standardization and harmonization.

This is a brief summary of the challenges facing national mapping agencies and other organizations interested in working together to create global environmental data sets. This work will continue into the future. We are receiving partial support for work in this area from the National Mapping Division of the U.S. Geological Survey.

2.2.2.1. Global data sets and natural disasters

To demonstrate the usefulness of global map data, a variety of global data sets were overlaid upon imagery of the flooding in Mozambique, which occurred in March and April 2000. Our goals were to demonstrate the use of global scale data for the assessment of local to regional scale natural disasters and to determine if we could employ these data sets within the context of a GIS to answer three questions:

1. How many people were affected by catastrophic flooding?
2. What was the total area of different land cover classes that could have been or were affected?
3. How much of the transportation routes were damaged or potentially could have been damaged in the area surrounding the Limpopo River Basin, Mozambique?

Several global datasets were found to be useful for this course scale analysis. Using global to regional scale data, a disaster's affects can be mapped and assessed. Using data published by several international aid organizations, as well as maps of the flood extent that they had made using different datasets and methodologies, it was determined that their differences were considerable - see Figure 2.2.2.1(a)

The flooding related to the Mozambique disaster events occurred as a result of five large tropical storms and hurricanes. Flooding covered a 50 mile wide area, displaced hundreds of thousands of people and devastated the recovering economy of Mozambique (Kriner, 2000; Murphy, 2000) - Figure 2.2.2.1(b). By April approximately 700 people were confirmed dead and nearly 1,000,000 were either homeless or in need of aid. Nearly 70 percent of Mozambique's 19 million people live in poverty, this heightens the necessity for international involvement when disaster strikes (CNN, 2000b; Datt et al., 2000). The timely reaction of international aid organizations, along with the aid organizations of governments from the surrounding countries could possibly have been hampered due to the unavailability and/or inaccessibility of accurate spatial information. It is unclear what information was available to those aid organizations at the time the events occurred, and on what data they based their assessment and planning. What is quite clear, however, is that the quality and value of the map data that is currently publicly available can be improved considerably by a globally consistent base dataset.

Derived image data products from weather satellites (Meteosat-7 and NOAA-14 AVHRR) were provided on several NASA/NOAA sponsored websites - see Figures 2.2.2.1 (b) and (c). Remote sensing imagery can be used to track the progression of hurricanes, to forecast rainfall intensities and to assess damage caused by flooding. USGS, NASA and the European Joint Research Center made Landsat 7 ETM+ as well as classified SPOT-4 image maps of the extent of the flooding available on the web as well - Figures 2.2.2.1(a) and (d). These images were useful for determining the extent of flooding involved, especially the SPOT-4 imagery, which was classified by the European Joint Research Center's Space Applications Institute to show the extent of the flood for two critical periods between hurricane events, 21-29 February 2000 and 1-10 March 2000 - Figure 2.2.2.1(d). Landsat TM imagery was acquired during two periods, before the flooding (August 22, 1999) and after the floods reached their maximum extent (March 1, 2000), clouds and shadows obscured some inundated areas but provided a very real perspective on the magnitude of the flooding.

Radar imagery is quite possibly the best sensor system available for mapping the flood extent of such a vast area because it is not impeded by clouds or atmospheric moisture and, due to the extreme difference in the reflective capacity of standing water and the volume scattering capacity of the closed canopies, has the capability of accurately mapping flooded vs. non flooded areas. Radarsat provided a series of images of the flooded area that demonstrated this capability - see Figure 2.2.2.1(e). Visible wavelength imagery (i.e. Landsat 7

ETM+ and Spot 4) also showed the extent of flooding well, and by using a time series composite the flooded areas can be reasonably well classified. Three datasets were found to be useful for deriving the aforementioned statistics; the 1-km resolution IGBP DisCover landcover dataset, the Gridded Population 4-km resolution dataset, a Landuse polygon coverage a stated scale of 1:200,000 and Digital Chart of the World coverage of transportation routes, political boundaries and coastline at 1:1,000,000 scale - see Figure 2.2.2.1(f). These data were incorporated into a GIS, the positional differences reconciled by rectification, reprojection and other means as necessary. All these layers were conformed to the boundary features of DCW in order to make comparisons possible.

In this type of study, the availability of data is one issue; the usability of these data is a different issue. Numerous research challenges exist as we try to reconcile scale, units and projections. RSRU/ISRG researchers are continuing to conduct research aimed at overcoming issues associated with these challenges.

Mapping the transportation, land cover and population density of the affected area provided a general picture of the flooded area but expectedly there were differences in the statistics derived from the base data using the flood extent maps provided by the various agencies - see Table 2.2.2.1(a). This mapping effort was meant to be a test of how well public domain globally available data from the internet could be used for disaster assessment. The flood extent maps provided by the aforementioned organizations were registered and used to clip the regional and global scale datasets discussed to see just how different the results would be. The non spatial data, i.e. current mortality statistics and other site specific information, were ubiquitous due to media attention but actual map data were not. For the most part the maps of Mozambique and the area of interest, found through numerous intensive searches, often did not have a date or source associated with them. Some of the web images were not intended for use in mapping but were never the less all there was available. It was interesting to note that a vast majority of the transportation routes, rivers and other important feature locations such as airports and towns on these maps were derived from one or two sources. These sources are Digital Chart of the World compiled by the Department of Defense and from Operational Navigational Charts, also compiled by the Department of Defense. These data may be out dated, especially in poorer third world countries, but there is no other base map from which individual mapping programs can begin to compile globally references locally usable spatial information.

Table 2.2.2.1(a): Comparison of results from data from different agencies

	World Food Program	State Department	Joint Research Centre
	No Date	March 3	February 21-29
Affected Area (km^2)	8,253	11,514	4,239
DCW Roads (km)	907	1,296	457
DCW Railroads (km)	121	200	63
Developed, Irrigated Cropland (km^2)	377	389	324
IGBP Class 12 (km^2)	695	1,152	310
IGBP Class 13 (km^2)	285	397	166
IGBP Class 14 (km^2)	743	542	234
Affected Population (people)	526,704	544,864	376,560

first global scale dataset used in this investigation because it contained landuse classes that encompassed human use. One of the original questions was to determine how, and more importantly where, the flooding had affected people; how many square kilometers of cropland were flooded? Where were the urban centers within the flooded areas? How much area of mixed use (i.e. seasonal agriculture or small crop farming) was flooded? The IGBP dataset uses 17 classes to describe the earth's land surface, this classification scheme lends itself well for applications where scientists in the earth processes modeling area as well as for regional ecosystem analysis fields can adapt it for their specific needs. There were three landuse landcover classes (IGBP classes 12, 13 and 14) that were of use in this course scale investigation into the uses of global to regional scale datasets for disaster assessment. Class 12 is the "Croplands" class, class 13 is the "Urban and Built-Up" class and class 14 is the "Cropland/Natural Vegetation Mosaic" class. These three classes were used to determine the number of square kilometers of land being actively used by people, or being utilized for various types of farming, that were affected by the flooding using the different flood extent boundaries.

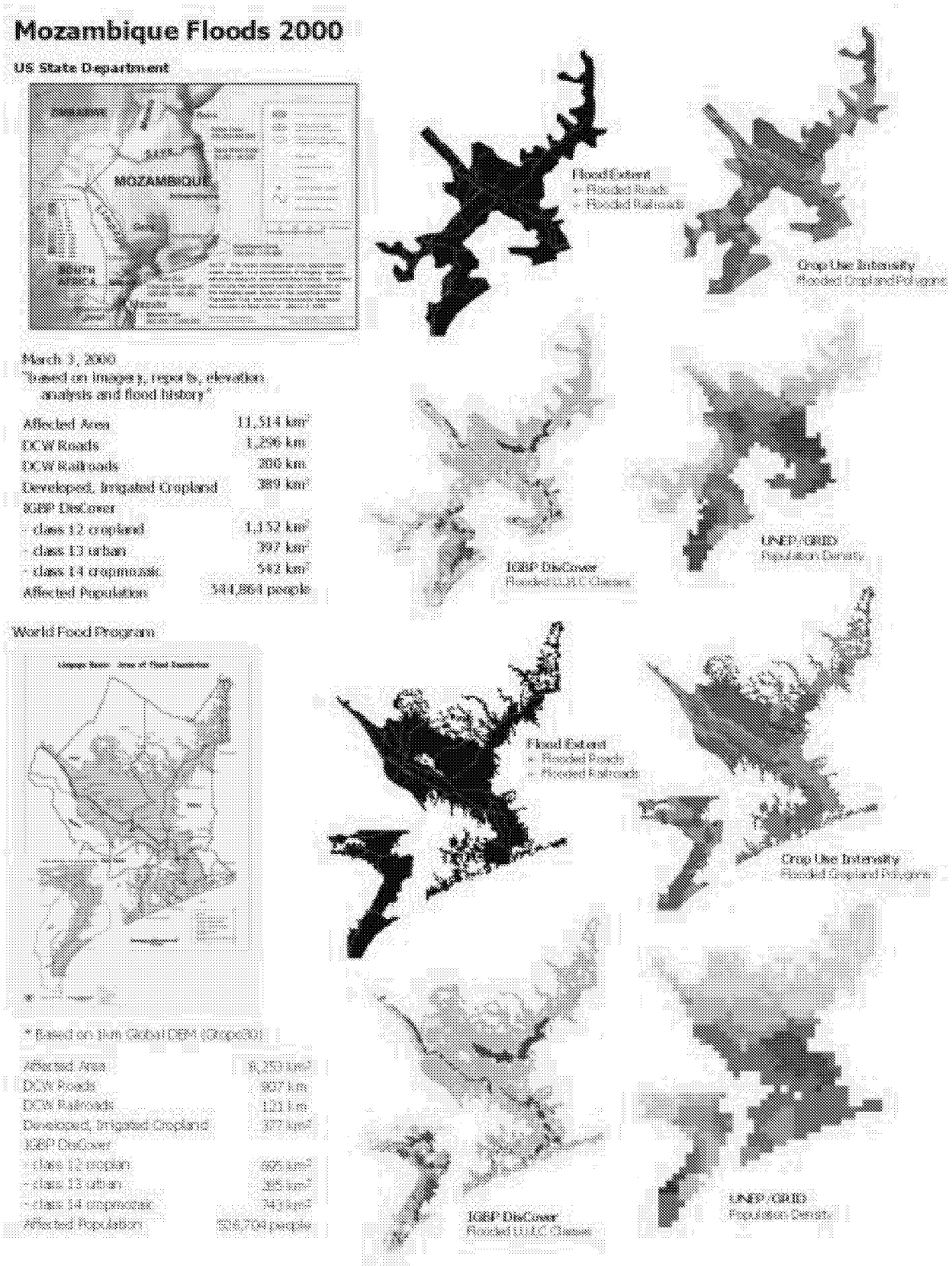


Figure 2.2.2.1(a): Comparison of results using maps and data provided by different organizations

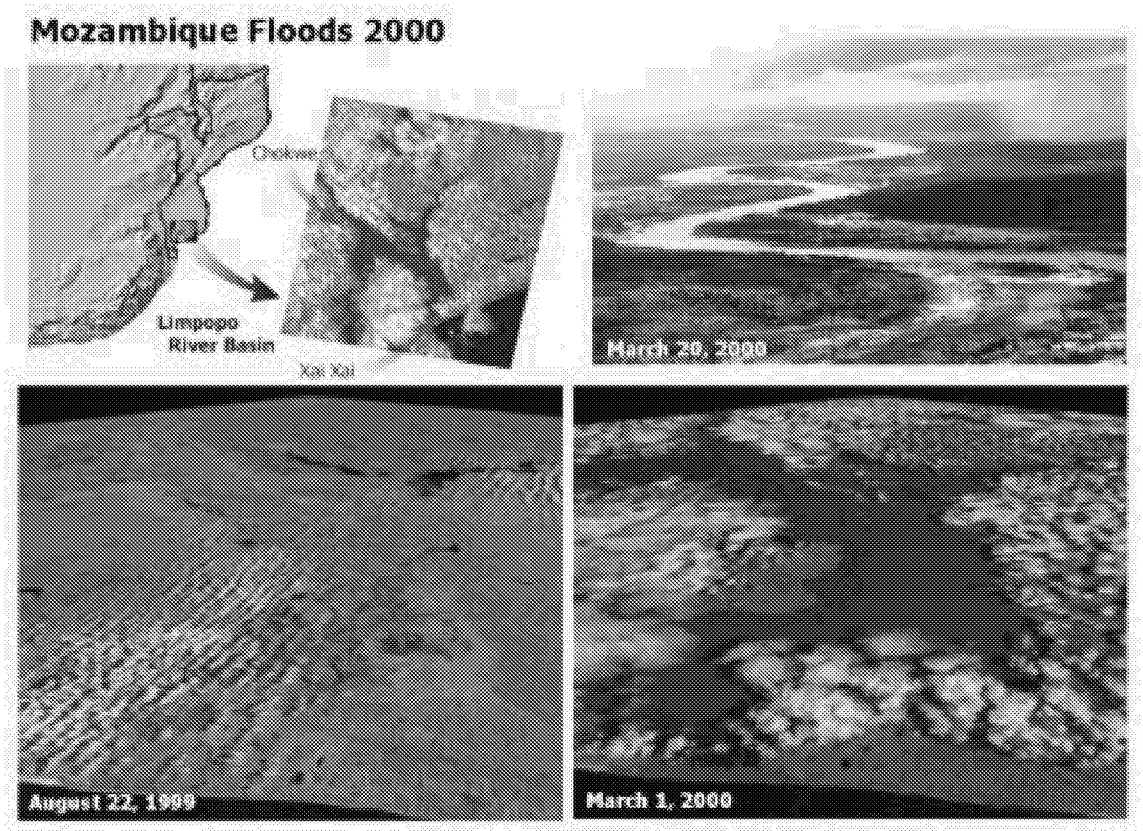

Mozambique Floods 2000
Limpopo
River Basin
Xai Xai
March 20, 2000
August 22, 1999
March 1, 2000
Perspective Views of Landsat 7 ETM+ Imagery Courtesy of NASA Goddard Scientific Visualization Studio
These images are of the same area on the east coast of Africa. Each image represents an area ~115 miles wide by ~100 miles north to south. Note that the lakes in the middle of the left image "grew" to represent a flooded area that is well over 50 miles wide in the right hand image.
Tropical Cyclone Leon -Eline
Acquired: 2/22/00 5:30 UTC
Meteosat - 7 Composite Imagery

Figure 2.2.1(b): Imagery of the extent of Mozambique flooding

Satellite imagery of the affected area was provided to the public by several agencies. Processed image map

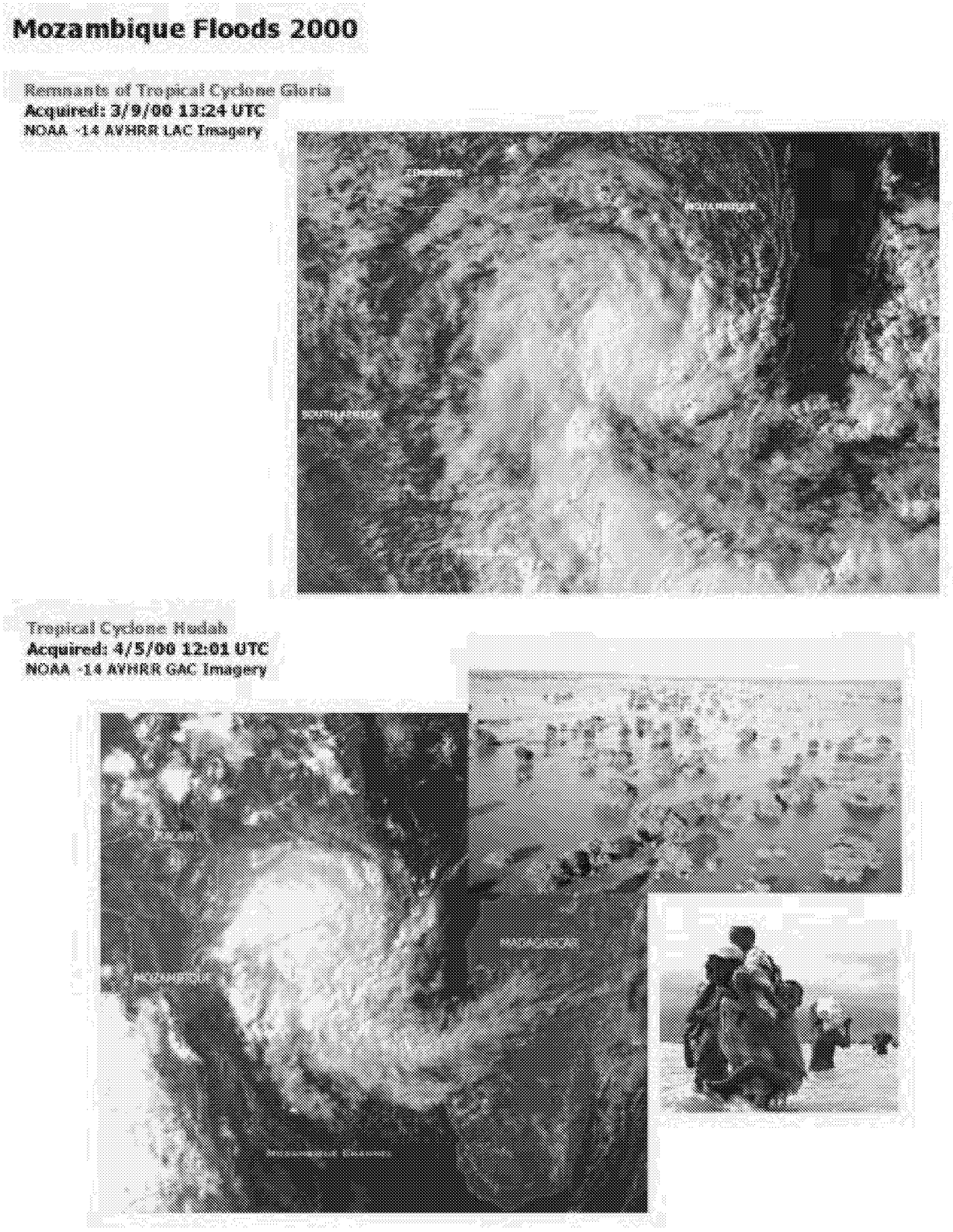
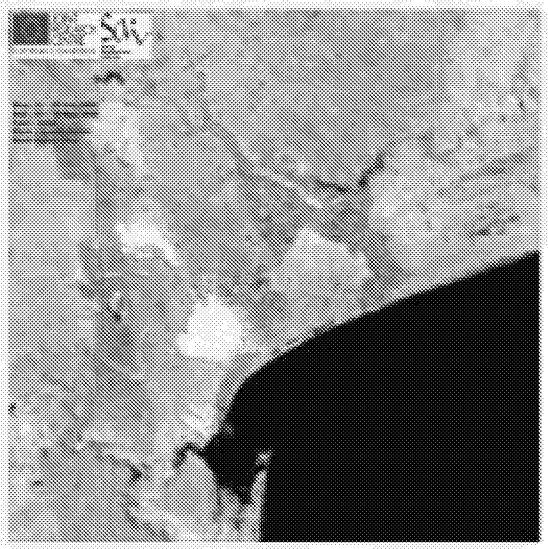

Mozambique Floods 2000
Remnants of Tropical Cyclone Gloria
Acquired: 3/9/00 13:24 UTC
NOAA -14 AVHRR LAC Imagery
Tropical Cyclone Hudah
Acquired: 4/5/00 12:01 UTC
NOAA -14 AVHRR GAC Imagery

Figure 2.2.2.1(c)

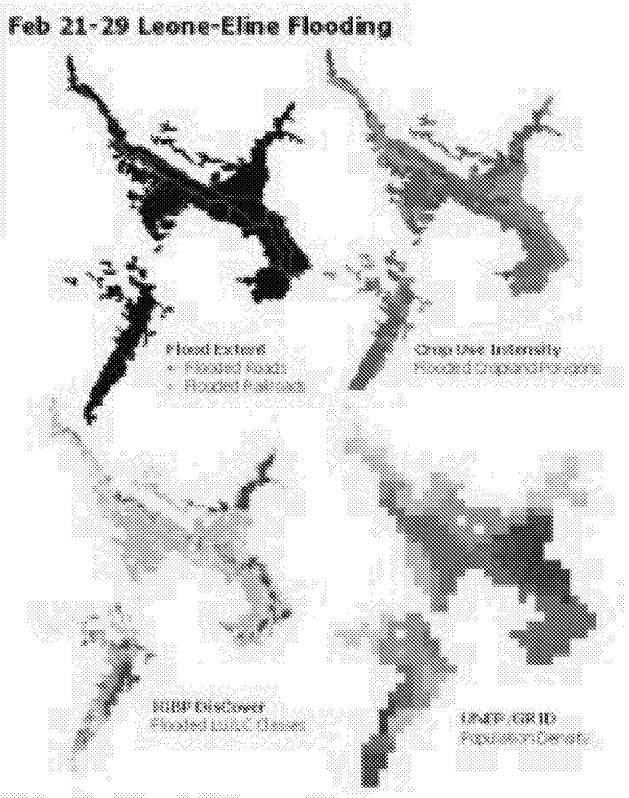
Mozambique Floods 2000

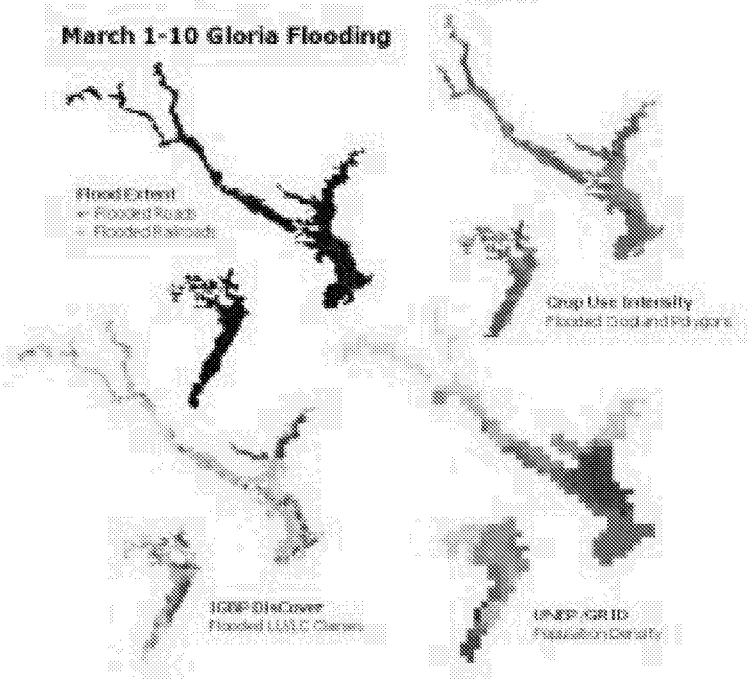
Flooding as of February and March from SPOT 4 Data



Produced with standard 10-day composite data from the VEGETATION instrument onboard SPOT 4.
- blue refers to the period 21-29 Feb. 2000
- red refers to the period 1-10 March 2000

The background image is a color composite made with a VEGETATION image of Nov.15, 1999





Feb 21-29 Leone-Eline Flooding

Affected Area	4,239 km²
DCW Roads	457 km
DCW Railroads	63 km
Developed, Irrigated Cropland	324 km²
IGBP DisCover	
- class 12 cropland	310 km²
- class 13 urban	166 km²
- class 14 cropmosaic	234 km²
Affect Population	376, 560 people

March 1-10 Gloria Flooding

Affected Area	3,648 km²
DCW Roads	375 km
DCW Railroads	41km
Developed Irrigated Cropland	222 km²
IGBP DisCover	
- class 12 cropland	373 km²
- class 13 urban	224 km²
- class 14 cropmosaic	274 km²
Affected Population	307,104 people

Figure 2.2.2.1(d)

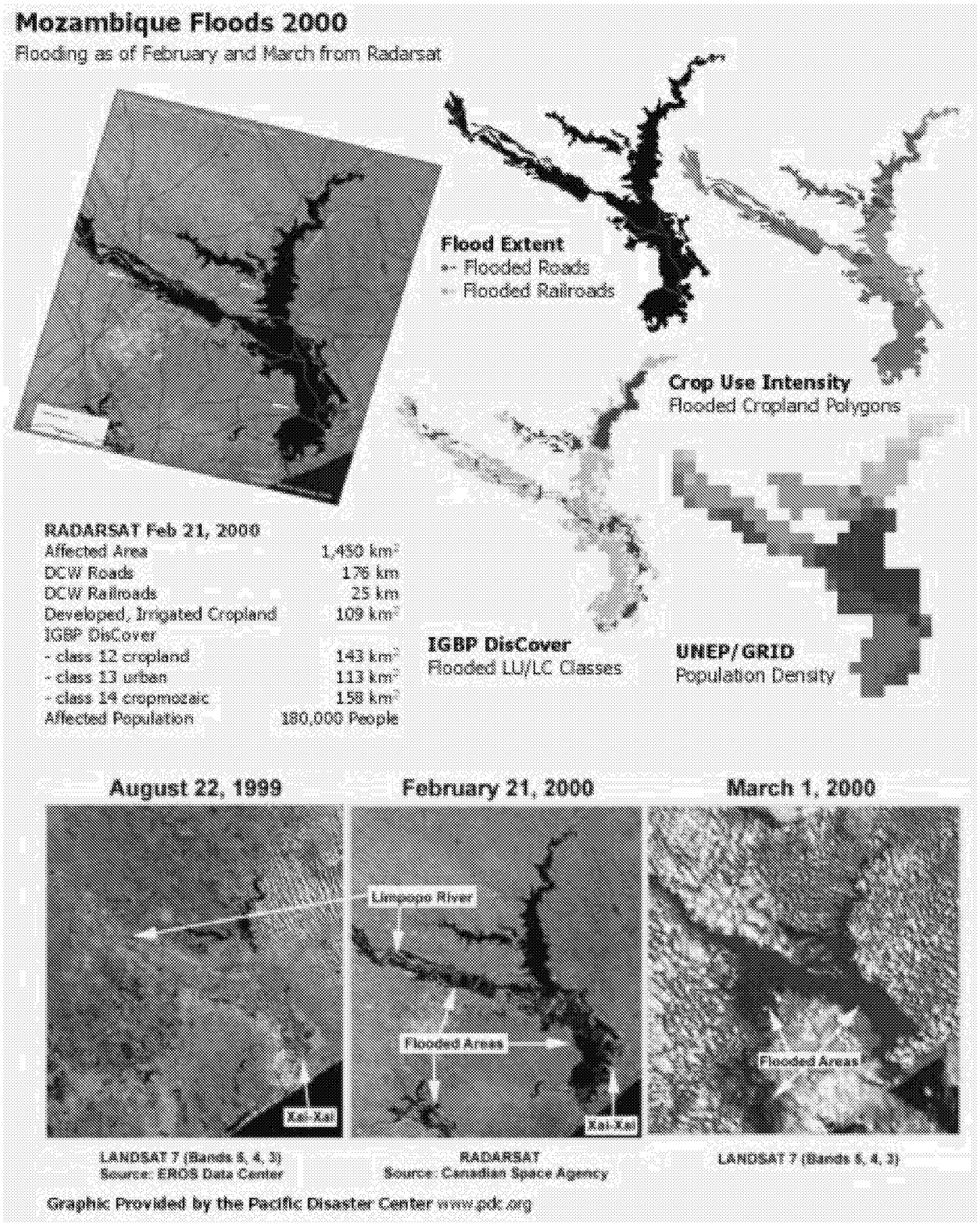


Figure 2.2.2.1(e)

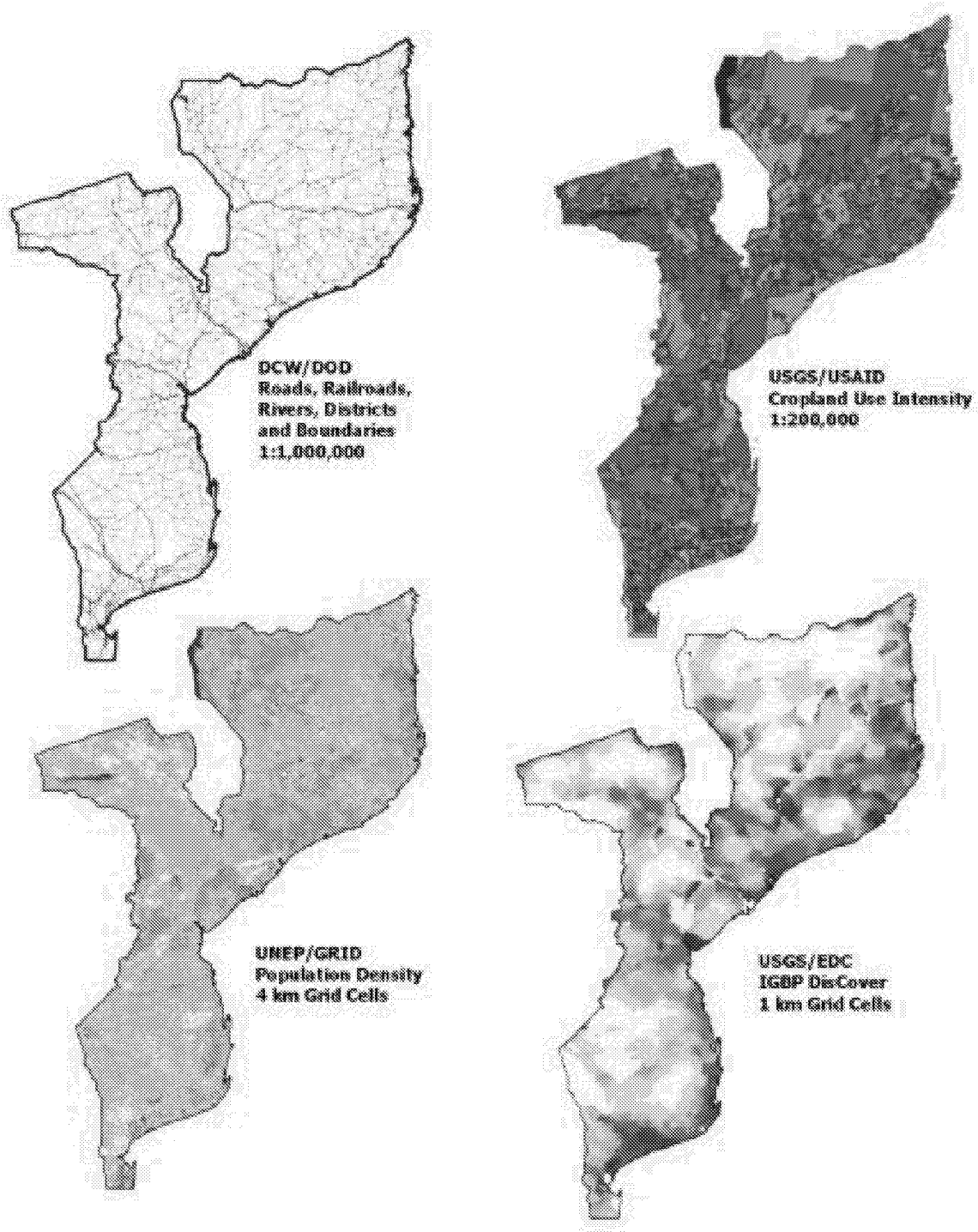


Figure 2.2.2.1(f)

The Gridded Population 4-km resolution dataset, downloaded from UNEP Grid, was used to assess both the distribution of population density and to see how many total people, according to a sum of the clipped grid cell values, the floods potentially affected. Population density is calculated based on an interpolation of point data values and difficult to collect and update in isolated areas of sub-Saharan Africa. At 4-km, this was the coarsest global scale dataset used for this general investigation. The maps produced by clipping this dataset with the different flood extent boundaries shows the population density and allowed for tabulating the population totals, but these figures are at best rough approximations due to the nature of the data. Civil wars, drought and natural disasters over the past decade have caused large population fluctuations between the six provinces within Mozambique, these factors add to the uncertainty of this dataset. All data issues aside, this dataset did provide a general depiction of the population distribution within the extent of the flooded area but the population totals calculated from each of the flood extent maps may be in error due to many reasons, including the course resolution.

A landuse polygon coverage at a stated scale of 1:200,000 downloaded from USGS Eros Data Center was the finest scale data used for this project. Being a well-documented vector polygon coverage made it easily to incorporate into a GIS with the other layers. This dataset, like the IGBP dataset, contained numerous classes for use by researchers and regional resource assessment applications that were not applicable for our purposes. Two classes were extracted from this dataset, the "Developed, Irrigated" and the "Flood Recessional Agriculture" classes. Using the flood extent coverages, these extracted polygons were clipped and the areas of each were totaled. These statistics are believed to be the most accurate because they were derived from 1:200,000 scale data. Unlike the IGBP DISCover data and the Gridded Population data, which were global in scale, this data set is only reasonably applicable for regional to local scale applications. This scale restriction for global datasets however is changing with the creation of new software technologies that offer the potential for high speed virtual roaming access, via the internet, to fine scale multilayer spatial information that is a part of a seamless globally consistent database. With the aid of high speed computing and large capacity storage hardware, scientists have the tools to access and work with global datasets.

Digital Chart of the World Level 1 coverages of transportation routes, political boundaries and coastlines were used, and served as the geographic reference for all of the other data sources collected. DCW is the digital representation of Operational Navigation Charts with an original scale of 1:1,000,000. This base cartographic map series was designed to support medium altitude route navigation, operational planning and intelligence briefings (Langaas and Tveite, 1995). Because DCW is a globally consistent vector database, it often serves as a geographic reference for many other global datasets and, most importantly, it is free and publicly available. The Roads, Railroads, and Political Boundaries of Mozambique were downloaded, imported and extracted. These layers were clipped with the different flood extent boundaries and the lengths of each set were tabulated. Because the political boundaries, rivers and roads of DCW were used as a geographic reference for registering the image maps of flood extent collected, it was feasible to coregister and compare them. Both the flood extent map produced by the World Food Program (using GTOPO30) and the map produced by the World Food Program (using "imagery, reports, elevation analysis and flood history") used these same features as a reference in their compilation. By sharing a common base layer these maps can be accessed in terms of their relative accuracy, as well as to compute statistics that can be used for disaster assessment.

2.2.2.2. Earthquake Hazard and Management on a Global, Regional, and Local Scale

Disaster prediction and management has been one of the keystone goals of the global map project since its inception. Because of the need to predict and plan for an international emergency as well as respond quickly, maintaining a database that allows for the understanding of how an disaster can affect an area as well as best means to cope with it after it happens is critical.

This research project concentrated on the availability and applicability of multi-scale data for the process of earthquake location prediction, determining which cities would be at risk, and how to best to prepare.

On a global scale, earthquakes affect major cities in almost every continent. Figure 2.2.2.2(a) shows the major cities with a population greater than 1,000,000 that are within 300km of an epicenter of a major earthquake (>6.0) within the last 50 years. Figure 2.2.2.2(b) is a chart identifying the number of major cities within 100km and 300km of known major faults. While some areas, particularly the west coast of the United States and Japan

have taken precautionary measures for earthquake related emergencies, the majority of cities in the world are not prepared for such a disaster. Critical issues for earthquake preparedness are knowledge of soil type and thickness under buildings, readiness of fire-fighting equipment for a situation where external power and water lines have been destroyed, determining and preparing evacuation routes to withstand a large earthquake, the storage of accessible emergency supplies, and the preparedness of Red Cross and other medical facilities for a large-scale disaster.

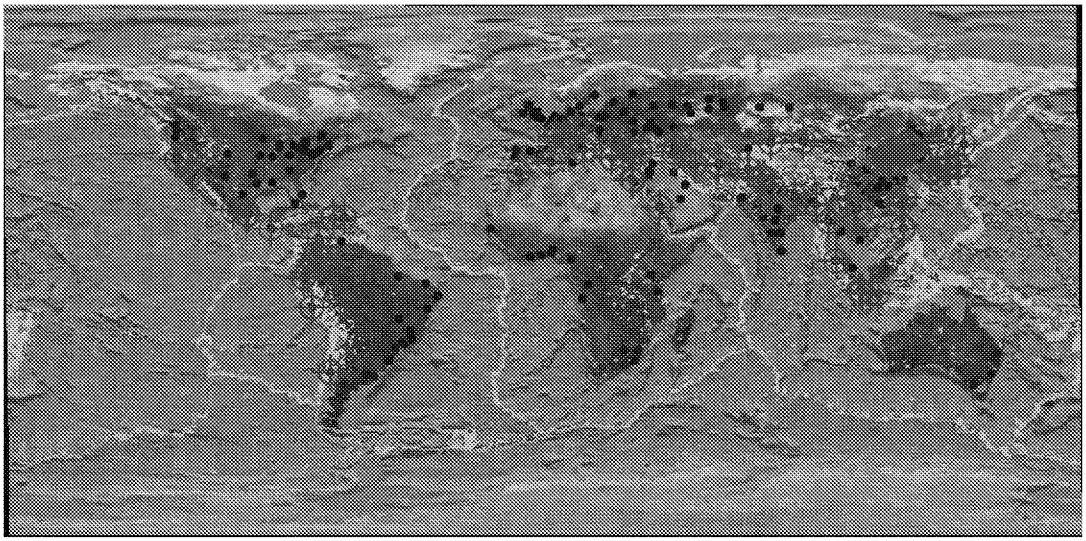


Figure 2.2.2.2(a): Cities Near Major Earthquake Epicenters (shown as red cross hairs. Blue dots are cities greater than 300km from and epicenter)

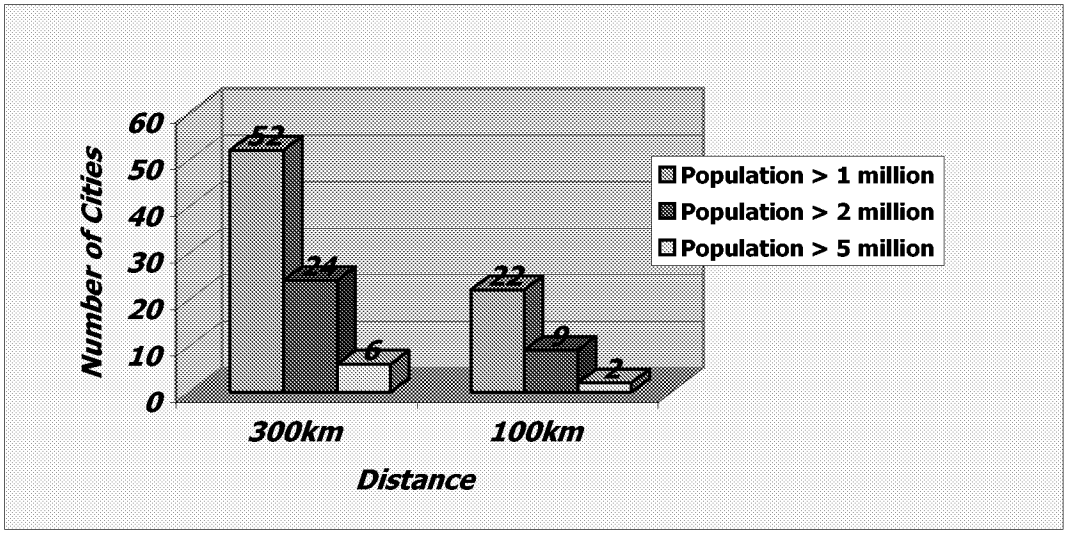


Figure 2.2.2.2(b): Cities by Population and Distance from Major Faultlines

The state of Kentucky's western border lies on the New Madrid fault line. This fault, although inactive for many decades produced some of the largest seismic activity ever recorded in 1811 and 1812. During a three-month time period five earthquakes measuring over 8.0 on the Richter scale accompanied by over 200 quakes

measuring between 4.5 and 8.0 obliterated the town of New Madrid, and caused severe damage in a several hundred kilometer radius. Fortunately, at that time the area was relatively undeveloped, so few lives were lost. At present, in the state of Kentucky alone, approximately 650,000 people live within 300km of the New Madrid epicenter - Figure 32.2.2.2(c). The analysis also revealed that western Kentucky has 1500 km of roads that may be damaged and 233 dams. In the case of a large earthquake many of these dams may fail sending huge floods toward both farms and cities in the watersheds below.

At a local scale the issues of earthquake preparedness and disaster management take on a new level of detail. As shown in the example below of San Francisco, the larger scale issues of evacuation routes and location of emergency facilities take on a new level of complexity. Figure 2.2.2.2(d) demonstrates how the issues of soil quality can adversely affect the road system and therefore possible evacuation. Because a large portion of the land in San Francisco is fill soil that is not stable, in the case of a strong earthquake liquefaction could not only damage buildings in these areas but also make the major roads impassable (Seekins, et al., 2000). This analysis shows how all major thoroughfares run through areas of high-risk soils and therefore San Francisco may be inaccessible by road in the case of a major earthquake.

This analysis, in conjunction with other analyses to determine areas sensitive to earthquake damage can be preformed only with data that is accessible. As has been shown in section 2.2.2.1, data accessibility over the Internet often presents problems. Data is often not available, more often than not data sources are unverifiable, and can be in direct conflict with other data sources for the area of interest. In the process of research for San Francisco, all data sources came from the Internet. Table 2.2.2.2(a) lists data sources that were deemed important in an analysis of risks and preparedness.

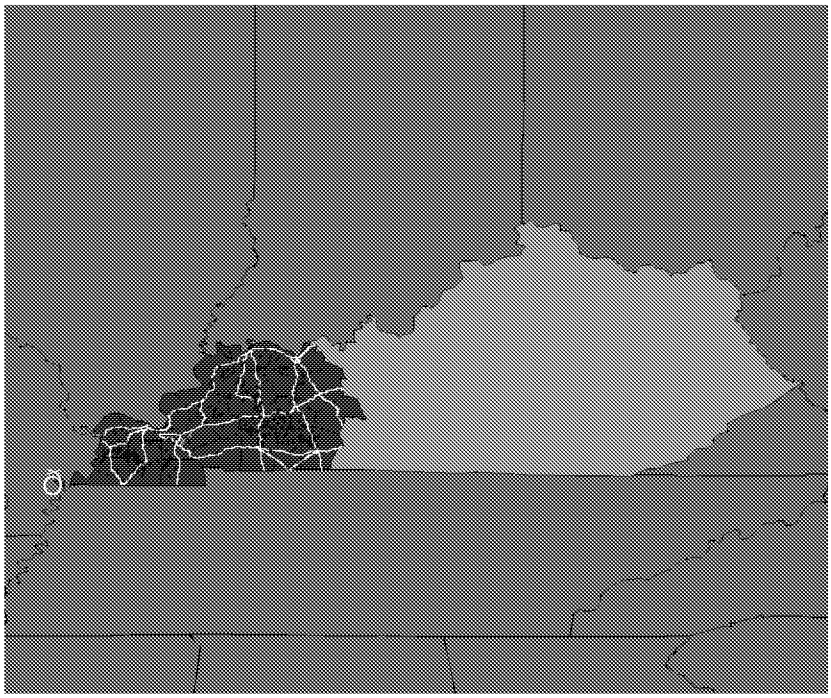


Figure 2.2.2.2(c): Affected Counties, Roads, and Dams in Kentucky within a 300km radius of the New Madrid Epicenter (shown as yellow cross hair). Population Affected: 644112; Roads in Area: 1529km; Dams in Area: 233

Figure 2.2.2.2(d): Soils with high-risk for earthquake damage with major access roads. (Roads in high-risk areas colored in red)

Table 2.2.2.2(a) Data accessibility for San Francisco earthquake preparedness and management

AVAILABLE ON THE WWW	NOT AVAILABLE ON WWW
▪ Highways ▪ Roads ▪ Fire Boat Range ▪ Aerial Photos ▪ Elevation Maps ▪ Soil Risks	▪ Water, Electric, Gas Mains ▪ Building Materials ▪ Zoning ▪ Fire Hydrant Location

2.2.3. Cooperative International Activities

ISRG/RSRU researchers continue to be involved in a variety of cooperative activities in the international arena. These have in the past included work with agencies such as the:

- United Nations Development Program;
- United Nations Environment Program;
- United Nations Institute for Training and Research (UNITAR);
- United Nations Educational Scientific and Cultural Organization (UNESCO);
- World Conservation Monitoring Center (WCMC);
- International Steering Committee for Global Mapping (ISCGM);
- Global Spatial Data Infrastructure (GSDI);
- International Society for Photogrammetry and Remote Sensing (ISPRS); and,
- Center for International Earth Science Information Network (CIESIN).

In this section we will break the focus of ISRG/RSRU participation into four specific areas. These areas include our work with Agencies of the United Nations, our work with global mapping and standards organizations such as the International Steering Committee for Global Mapping and the Global Spatial Data Infrastructure, Center for International Earth Science Information Network, our work with the, and our work with the International Society for Photogrammetry and Remote Sensing.

2.2.3.1. United Nations Agencies

It is important to note here that Dr. Timothy W. Foresman, a UCSB graduate and former RSRU researcher, is now Director of UNEP's Division of Environmental Information, Assessment and Early Warning. As such, he is now responsible for the management oversight of all UNEP/GRID nodes worldwide. Dr. Foresman has indicated that he sees a role for RSRU/ISRG researchers in working with and advising GRID in a broader sense in the future. Dr. Foresman has discussed opportunities for our graduate students to work on short-term projects for UNEP. We at UCSB look forward to working with Dr. Foresman in Nairobi in the future.

2.2.3.2. Global Mapping and Standards Activities

ISCGM

In 1992, the Ministry of Construction of Japan began to advocate the global mapping concept. As stated above in this proposal, the fundamental basis of this concept is to develop global scale geographic information through international cooperation (particularly among National Mapping Organizations [NMOs; sometimes also referred to as National Mapping Agencies [NMAs]). Since its formation in 1992 the concept of global mapping has obtained support from many countries. Efforts are now underway to acquire and/or create global scale map products under the auspices of an International Steering Committee for Global Mapping (ISCGM). As seen in Section 2.2.2 of this proposal, ISCGM is composed of the heads of mapping organizations of 16 countries, as well as representatives (advisors and observers) from international organizations, other national agencies, selected industrial concerns, and academic institutions. Key to ISCGM's efforts to create globally consistent thematic map products is the participation of national mapping organizations (Secretariat of International Steering Committee for Global Mapping, 1996(a); Secretariat of International Steering Committee for Global Mapping, 1996(b); Secretariat of International Steering Committee for Global Mapping, 1997; Secretariat of International Steering Committee for Global Mapping, 1998(b); Secretariat of International Steering Committee for Global Mapping, 1998(a); Secretariat of International Steering Committee for Global Mapping, 1999).

ISCGM was formally established at a meeting in Tsukuba, Japan in February 1996. There have been seven subsequent meetings to this point. These meetings were:

- Tsukuba, Japan in February 1996
- Santa Barbara, California in November 1996
- Gifu, Japan in November 1997
- Sioux Falls, South Dakota in June 1998
- Canberra, Australia in November 1998
- Cambridge, England in July 1999.
- Cape Town, South Africa in March 2000
- Cartagena, Colombia in May 2001
- Budapest, Hungary in September 2002 (scheduled)

The primary purpose of ISCGM is to examine measures that concerned national, regional, and international organizations can take to foster the development of Global Mapping; mapping that will facilitate the implementation of global agreements and conventions for the protection of biodiversity, mitigation of natural disasters and that will encourage economic growth within the context of sustainable development. The principle activity of the ISCGM, in addition to being a forum for facilitating communication and collaboration among NMOs/NMAs, is the Global Map project discussed elsewhere in this proposal.

The objective of global mapping is to help us understand the nature and the magnitude of global environmental challenges facing society today; and to facilitate the identification of future challenges. As currently envisioned, global map thematic data sets, i.e. elevation, land cover, and transportation, will provide coverage of the whole land area of the earth at 1km ground resolution. Each theme will be represented in a consistent manner and distribution of global map data will be unrestricted and available to anyone at the marginal costs to reproduce and supply the data. Global Map is being produced in a digital format for easy handling by computer and its content is equivalent to conventional maps at scales of 1:1,000,000. Specifically, Global Map will be composed of the following thematic layers: elevation, vegetation, land-use, drainage systems, transportation, and administrative boundaries. Current plans are that these data will be updated at approximately five-year intervals to facilitate the monitoring of changes occurring in our global environment. A portion of our work in the coming year will be focused around the year 2005 update of Global Map 2000.

Professor Estes continued to be active in the ISCGM as the Chairman until his death in March 2001. Previously, at the 7th ISCGM meeting, Dr. Estes was elected to Chair the ISCGM until the next meeting in Cartagena, Colombia, in May 2001. During the meeting in May, and at previous ad hoc meetings, a Chair Selection Committee met. Ms. Kline has been actively involved in this process. In addition, she has been nominated and accepted the position as Assistant Secretary General of the ISCGM.

GSDI

The Global Spatial Data Infrastructure (GSDI) activity is comprised of a group of individuals representing national mapping agencies, international organizations, and standards organizations. GSDI was defined at the second GSDI Conference (1997) as "the policies, organizational remits, data, technologies, standards, delivery mechanisms, and financial and human resources necessary to ensure that those working at the global and regional scale are not impeded in meeting their objectives."

Personnel from organizations and individuals interested in the establishment of a GSDI first met September 1996 in Bonn, Germany, and focused on "The Emerging GSDI." A second meeting was held in October 1997, Chapel Hill, North Carolina, and the focus was "Towards Sustainable Development Worldwide." At Chapel Hill, GSDI was defined, as noted above. Also, "one of the central findings of the 2nd GSDI Conference is that the GSDI is of vital importance to implementation of Agenda 21 of the Rio Summit and to multi-national environmental conventions and that it should be placed as central support for decision making before the meeting of the UN Commission on Sustainable Development in 2001. Further, the GSDI is critical to the attainment of substantial and sustainable development in both the developed and developing countries of the world" (1998). The third meeting, in Canberra, Australia, November 1998, focused on the "Policy and Organisational Framework for a GSDI." A primary finding from this third meeting is that "National Mapping Organisations/Agencies play a key role in ensuring that accurate, up-to-date geospatial framework data are developed and maintained. Such data are key to, among others, the promotion of sustainable economic development, improvement of environmental quality, resource management, upgrading public health and safety, modernization of governments at local, national or regional scales, and the responses to natural and other disasters. Therefore such organizations play a vital role in facilitating the development of a GSDI" (1998). Dr. Estes played a vital role in the development of the GSDI concept and the organization, and RSRG personnel continue to participate in these activities.

2.2.3.3. Center for International Earth Science Information Network

In 1999, RSRU personnel were involved in the outlining of a workshop on Remote Sensing and Environmental Treaties: Building More Effective Linkages. This effort was led by the Center for International Earth Science Information Network. During the year 2000, RSRU personnel worked with CIESIN personnel on the production of a background paper titled, "International Environmental Agreements and Remote Sensing Technologies." This paper was made available to the participants before the workshop, scheduled for December 2000 in Washington, DC. Due to travel difficulties RSRU/ISRG personnel were unable to participate in this workshop. However, an article tentatively titled "Remote Sensing Applications in Support of Environmental Treaties" by Alex de Sherbinin of CIESIN, Karen D. Kline of the RSRU, and Kal Raustiala of UCLA Law School has been submitted to Environment.

2.2.3.4. International Society for Photogrammetry and Remote Sensing

In November 1999, Dr. Estes and Ms. Kline attended a working meeting held by Working Group IV/6 of the International Society for Photogrammetry and Remote Sensing (ISPRS) to develop a book on global environmental data sets. RSRU personnel have been involved in three of the chapters of this book (Global Environmental Databases: Present Situation; Future Directions): Introduction (Kline et al., 2000), A Reference Framework for Global Environmental Data (Anderson and Kline, 2000), and Large-Area Land Cover Characterization (Loveland et al., 2000). This book was released and presented at the 19th ISPRS Congress and Exhibition, held July 16-23, 2000, in Amsterdam, the Netherlands. Copies of the three chapters RSRU were involved in producing are available in the appendix.

2.2.4. Managed Areas Mapping

The Managed Areas Database (MAD) is a comprehensive regional scale vector database of managed lands within the conterminous United States. The compilation of this database began in 1993 and took nearly three years to complete. The motivation for this project came from resource managers and a need for a GIS database of protected (i.e. National/State Parks or National/State Research Areas) and unprotected managed area boundaries (i.e. Military Reservations or Bureau of Reclamation Lands). As the project progressed it became clear that MAD had the potential of being useful for a diverse range of applications and research projects. Since its release in 1996 it has been widely disseminated and continues to be the only database of its kind publicly available for the conterminous United States. Three journal articles, two Masters Theses and numerous derived products have utilized this database.

In the past year MAD has been downloaded more than 100 times and used for a diverse range of applications. These includes a consulting group working for oil and gas companies studying routing alternatives for pipelines, air force personnel interested in planning airspace boundaries around ecologically sensitive managed areas and by federal level resource managers for making display graphics. Support for this database continues despite there being no update effort currently underway or planned for the coming year. A serious update effort would require dedicated resources and skilled personnel to accomplish. Currently ISRG researchers are continuing to answer inquires and perform selected GIS operations (such as reprojecting and subsetting) on the MAD data base, the MAD database is being maintained in an operational sense. The databases gathered for the purposes of updating MAD have been archived and in certain instances distributed to users interested in alternative databases of managed areas boundaries at finer scale where such data are available. Certain users have encountered difficulties using MAD in certain applications due to its course scale, others have found discrepancies with other datasets and still others have found it to be perfect for their intended purpose.

Updating this database has proceeded on a limited basis due to the volume of available data and the effort, in terms of time and funding, required. It has become clear that updating the boundaries of MAD will be a continuous and time consuming process because areas change in extent, shape and designation almost every year. This rearranging, renaming and changing of managed areas boundaries has become a serious problem for regional mapping efforts due to the existence of multiple databases of different scale compiled by different agencies with different agendas. Efforts to synchronize state mapping efforts have encountered resistance due to each state's individual needs, mapping capabilities and procedures. This is where MAD fills a unique role; it is nationally coherent and has course scale boundaries for the managed areas of every state. Although it is true that the database in out of date, it remains as the only source for regional scale boundaries of managed areas for the conterminous united states. Many users have found MAD to be extremely useful in this regard; it is straightforward to work with and is well documented in terms of source data used and the relative accuracy of the database.

Users of the MAD database often inquire about the accuracy of the boundaries. The data set was compiled from different sources the stated accuracy is that of the least accurate source (1km) and users often have applications that require more accurate data. In such cases users are provided more accurate data from the extensive archive of databases collected as part of the updating process or they are directed to more accurate local scale sources. GIS database accessibility has grown considerably in the past few years, this has spurred interest in updating MAD by other agencies due to the need for a coherent base from which to begin the

monumental task of assimilating the brethren of GIS data available into a coherent, up to date regional scale database which will include new boundaries, names and designations that are not currently in MAD. During the past four years users have been able to contact the people directly responsible for this database via telephone or email. In most cases users received the assistance with the data that they need.

This database covers the entire conterminous United States at a regional scale; this makes it usable by most basic desktop systems for making maps, posters and graphics. In such cases where the user is limited by the capabilities of their hardware/software some of the processing has been performed here using our facilities. Desktop GIS mapping software, such as ESRI's Arcview and Microsoft's MapObjects, have been developed to the point where just about anyone familiar with using a computer can import, display and query GIS databases such as MAD. These new users (at times not familiar with GIS data, scale and software functionality) have received the assistance and information they need to use the data appropriately. It is hoped that by transitioning this data base to a public mapping agency these users will continue to receive needed support.

2.2.5. Integration of Remotely Sensed Data and Wildlife Survey to Asses Landscape Scale Habitat Quality

The intent of this research is to focus on the application of aerial and satellite imagery to determining the greater landscape affects on the long-term ecosystem viability. By using field data that not only determines the actual vegetation and landcover type of an area, but also the diversity of wildlife, a map can be generated showing the biodiversity at a given location. Using large-scale Landsat ETM imagery, in conjunction with datasets of roads, buildings, and other human influence analysis can be performed to determine what the proper scale for study on factors affecting local biodiversity is. The study area, the coastal area between Santa Barbara, CA and the northern extent of Vandenberg Air Force Base is commonly referred to as the Gaviota Coast. (See Figure 2.2.5(a).

Specifically, this study has four goals:

1. Outline landscape scale factors that can affect local biodiversity
2. Provide a high-resolution landcover database of an area presently being considered for reserve status as a National Park, National Seashore, or a State Park.
3. Make recommendations for the minimum size of preserve to protect the biodiversity and endangered species of the area.
4. Establish a replicable methodology for analyzing large areas for best reserve design and placement that accounts for all biodiversity within a minimum area.

The significance of this study is several-fold. The scientific question of how much land is necessary to support the wildlife diversity historically found in area is one of the most pressing questions in modern conservation (Hollander et al. 1995). This study is directly applicable to research in progress conducted by the County of Santa Barbara, and the National Parks Service to locate possible National Parks, National Seashores, and other valuable natural reserves within the Gaviota Coast area. Because, the parties conducting research are interested in maintaining biodiversity within the area, and because the County of Santa Barbara is under pressure to develop large areas of the Gaviota Coast for housing, there is a pressing need to understand what the minimum size of reserve need be to protect the sensitive species and diversity found in the area.

Research in the last year has focused on data acquisition and research for proper methods to analyze the acquired datasets. Research generated a series of alterations in methodology from the effort proposed last year. Whereas previously, I intended to perform a landcover and metrics analysis on a single Landsat ETM image (Figure 2.2.5(b).), it became apparent through the course of researching methodologies and attempting to perform the analysis that this methodology was not comprehensive enough to extract meaningful results from the given dataset.

Automated classification of the ETM scene proved to be inconclusive, so a methodology was derived using a combination of automated classification, aerial photo interpretation, and spatial modeling based on ancillary data. To use this methodology, several additional datasets were gathered. USGS Digital Orthophoto Quadrangles (DOQQs) were collected for the entire study area. These photos, having a spatial resolution of approximately 3m allow for interpretation of landcover features easily by a trained person. Additionally, datasets of roads, buildings, known streams, and political boundaries were collected for use in the modeling process.

Each of these datasets were given geographic coordinates based on ground control points (GCPs). For this process, a high-accuracy GPS unit was assembled to visit and record locations within the study site that also appeared in the dataset. Section 2.3.6 of this document describes an accuracy assessment of this GPS equipment. The coordinates of each location were catalogued and assigned to the corresponding point on the dataset.

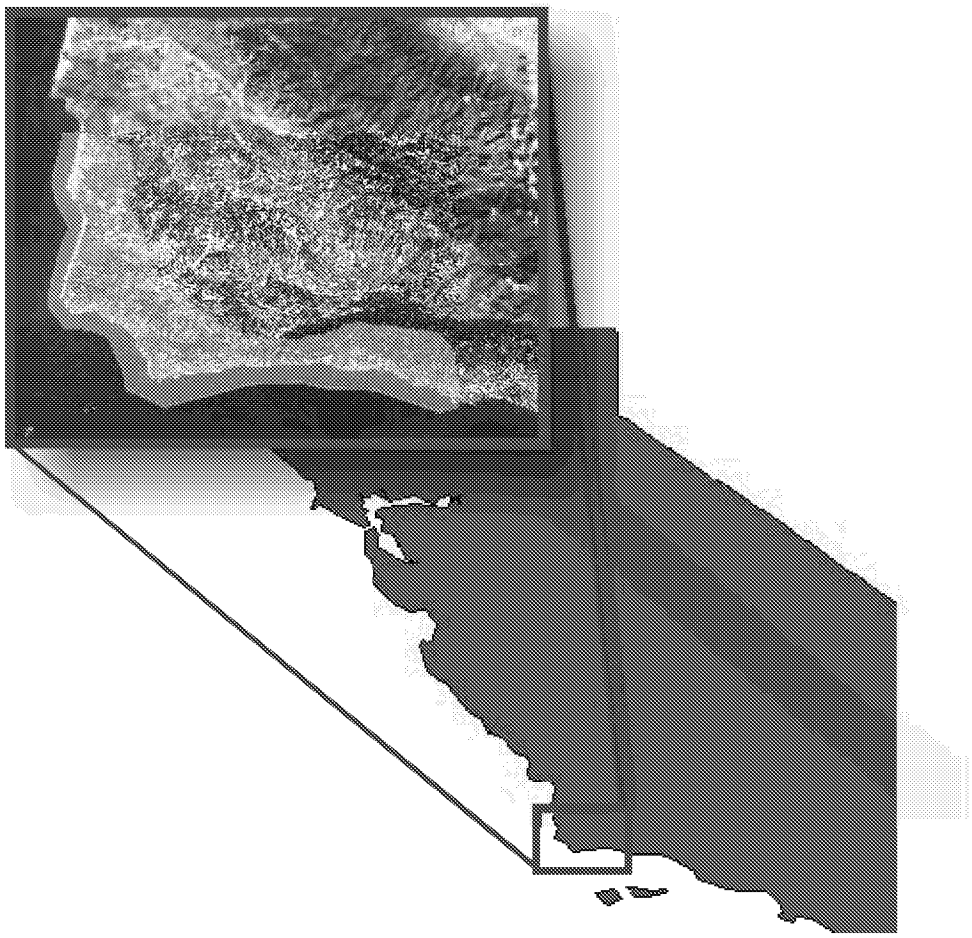


Figure 2.2.5(a)

Principal components analysis (PCA) is a commonly used process by which multiple datasets can be examined for correlation (Bailey and Gatrell, 1996). PCA was applied to the different bands of the Landsat ETM image to help with interpretation (Figure 2.2.(c).). Because the Landsat images are mulitspectral data that represent reflectance in blue, red, green, and multiple infrared wavelengths, an analysis can be performed to determine if there is a correlation the relative amounts of each color in the scene. The result of PCA is a more concise image that describes enhances the contrast between different elements in the scene.

The landcover classification system was decided on for the purpose of this study. A modified version of the California Vegetation classification (Holland and Keil 1995) suited the area best (Table 1). This classification system, designed specifically for the vegetation of California, is hierarchical and therefore allows the resulting landcover map to describe in as much detail as was obtainable from the datasets.

Research in this last year has clarified the methods for classifying ETM imagery for the purpose of landcover analysis. Additionally, a clear protocol for wildlife sampling has been derived from commonly used bird sampling methods (Gallo et al, 2000). This methodology allows for integration of other field workers' previous and future sampling efforts with this research.

Figure 2.2.5(b). Landsat ETM Image Showing Infrared Reflectance of Subset of the Study Site

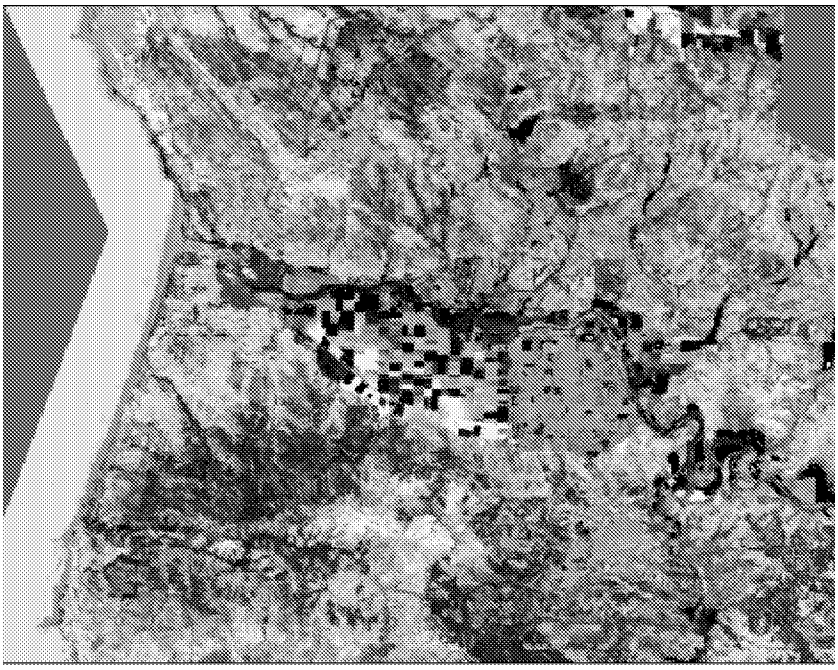


Figure 2.2.5(c). Principal Components Analysis Image of Subset of Study Site (Note difference contrast between this and figure 2 which show the same area. The green areas are sand and urban, blue areas, largely cropland, and red areas various native vegetation types.

Table 2.2.5(a). Primary Landcover Classification System (Modified from Holland and Keil, 1995)

Level 1 Communities	Level 2 Communities
Marine Aquatic Communities	Subtidal and Intertidal
	Coastal Estuarine
	Coastal Salt Marsh
Coastal Sand Dune Communities	Pioneer Dune
	Dune Scrub
Coastal Scrub Communities	Southern Coastal Scrub
	Sea-bluff Coastal Scrub
Chaparral Communities	Mixed Chaparral
	Chamisal Chaparral
	Manzanita Chaparral
	Ceanothus Chaparral
	Scrub Oak Chaparral
	Serpentine Chaparral
	Semidesert Chaparral
Grassland Communities	Native Bunchgrass
	Valley and Southern Grassland
	Non-native Grassland
Closed-cone Coniferous Forest Communities	Coastal Closed-cone Pine Forest
Mixed Evergreen Forest Communities	Central or Southern California Mixed Evergreen Forest
Oak Woodland Communities	Coastal Live Oak Woodlands
	Valley Oak Woodlands
	Foothill Woodlands
Riparian Communities	Valley and Foothill Riparian
Anthropogenic Communities	High-density Urban
	Low-density Urban
	Cropland

2.6. Automated Topographic Feature Analysis

Using Triangular Irregular Networks (TINs) and surface interpolation methods, accurate Digital Elevation Models (DEMs) were created from the digitized contour of historic topographic maps covering the La Conchita community, a coastal zone area located 15 miles south of Santa Barbara, California. Using the historical DEMs as the basis for comparison, aerial photography and other ancillary data were used for the analysis of the factors involved in a landslide event.

The data used for this project stem from the mapping of an area where a landslide destroyed nine homes La Conchita in 1995. Landslides, among other forms of natural disaster, affect many Southern California Coastal communities. The causal agent in a majority of landslides is groundwater that infiltrates the surface and increases the pore pressure, which reduces the soil's resistance to shear stress that results from the force of gravity. It was alleged that excessive irrigation was the cause of the landslide in this study, the results of our analysis show that there is a long history of landslides in this area with numerous contributing factors; the least important of which was local agricultural irrigation. It is believed that the critical causal agent in this slide event (aside from the unstable local geology) was intense rainfall that occurred during the "100-year storm" of January 1995.

Landslide analysis is a multidisciplinary endeavor that relies on numerous fields of expertise. Airphoto interpreters document the chronology of events leading up to the slide using historical photography. Pedologists and hydrologists gather data from soil samples and subsurface groundwater measurement devices. Geologists infer subsurface geologic structure and internal forcing. All these data are then synthesized and a database is created. Assessment of landslide hazards and analysis of mass wasting events have benefited greatly from the application of the processing and analysis capabilities of Geographic Information Systems. Surface modeling and data integration capabilities of GIS software and advances in digital photogrammetry have revolutionized the field of landslide analysis. Processing efficiency, improved user interface design and the technological ability to quickly compute complex trigonometric solutions have greatly enhanced landslide analysis by eliminating once tedious time consuming manual tasks and allowing for the visualization of fully integrated three dimensional geographic databases.

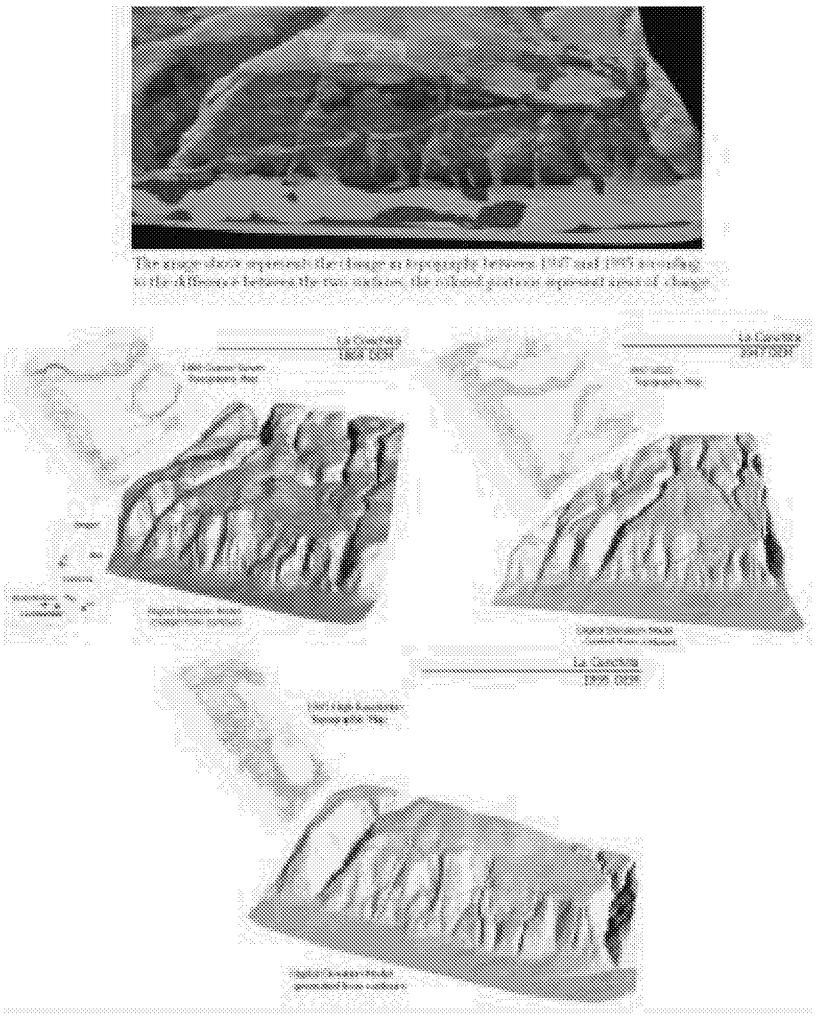


Figure 2.2.6(a). Overlays of three-dimensional surfaces and Digital Elevation Models, La Conchita, CA.

This research explored several of the techniques used for creating three-dimensional surfaces from paper maps and addressed data integration issues related to landslide investigations. A 1:10,000 Coastal Survey map manually plotted from ground level surveys conducted in 1869 and a USGS 1:24,000 Quadrangle plotted using benchmarks and stereo photography in 1947 were used to create the DEMs used in this analysis. Digital contours generated by a professional geotechnical engineering firm from high-resolution stereo photos taken in 1995 were used for comparison with the surfaces generated from the 1869 and 1947 maps as well. Errors associated with differences in methods and coregistation impose limits on the quantitative comparability of the

DEMs generated from the historic contour maps and the high resolution contours. The overlay of the three dimensional surfaces does however show several interesting changes in topography that are verifiable by aerial photography (Figure 2.2.6(a).) Error correction was aided by the use of macro language scripts that iteratively refined the TIN generated from the contours by testing all possible combinations of parameters until the optimum set was reached. Other data sources were also incorporated into the GIS: aerial photography of various scales dating as far back as 1928, detailed geologic surveys conducted over the past two decades and hydrologic surfaces derived from bore hole data.

2.2.7. Remote Sensing and Spatial Metrics - Urban Area Analysis

Over 70 % percent of the population in developed countries lives in urbanized areas. Recent developments of population growth, migration into urban regions and rising ecological problems require advanced methods for city planners, economists, ecologists and resource managers to support sustainable development of these fast-changing regions. Accurate decision-making requires extensive knowledge about the causes, the chronological development and the effects of these processes. To support this decision-making process, different methods of data acquisition, analysis and evaluation are employed. Remote sensing technology allows the user to derive spatial data in high temporal and spatial resolution. The ISRG research conducted during the current year has been focused on the use of remote sensing and spatial metric information for applied urban analysis. This research has been conducted in conjunction with Mr. Martin Herold at the Friedrich Schiller University, Jena, Germany.

This current research has been a continuation of work focused on this topic conducted during the past two years. The goal during this year has been to improve and extend the results and approaches of ongoing ISRG research on this topic. This year's research activities had three principal goals:

1. Complete and refine our remote sensing/landscape metrics analysis
2. Development and evaluation of urban metrics and indices
3. Application and optimization for end user requirements

Our work has fulfilled Goals 1 and 2; we were less successful at focusing on Goal 3 and this will continue to be a principal objective to be completed during next year's research. A technical summary of this work follows.

Recent research has identified a number of different approaches for data acquisition and land use characterization and analysis in which remote sensing imagery is used as source data in the derivation of spatial data sets with high temporal and spatial resolution. Additionally, several studies performed during the last fifteen years demonstrate the high potential of remote sensing data as source information specifically useful for analysis of the urban/suburban environment:

1) Urban climatic investigations using thermal- and microwave remote sensing (Kim, 1992; Quattrochi & Ridd, 1994; Nichol, 1996; Basly et al.1997; Abbate, 1997)
2) Derivation of 3-D city models with photogrammetric analyses (Kim and Muller, 1995; Sinning-Meister et al. 1996; Zavoianu and Nitu, 1998)
3) Monitoring of urban land use changes and urban growth from optical satellite data and airphotos (Colwell, 1985; Meaille and Wald, 1994; Galema and Galema, 1991; Changda et al., 1994)
4) Mapping of urban infrastructure with optical satellite data and airphotos (Wang, 1992; Jensen et al., 1994)
5) Use of optical remote sensing data in local and regional planning (Ehlers et al., 1990; Meinel et al., 1998)
6) Estimation of population density from nighttime acquired optical satellite data (Imhoff et al., 1997)

A limitation in the application of remote sensing to urban regional analysis is the spatial heterogeneity found in urban land cover. Welch (1982) determined that remote sensor data having a spatial resolution 5 meters or finer was required in order to perform accurate urban land use analyses. The USGS land use/cover classification scheme (Anderson et al., 1976), identifies seven discrete urban land use classes at Level II. To accurately derive urban land use with this type of high thematic accuracy, the use of only the spectral response

and widely used "per-pixel" classifiers (e.g. Maximum Likelihood) are not sufficient (Barnsley et al., 1993; Mesev, 1998).

Several different approaches have been developed to improve the thematic accuracy of urban land use analyses by utilizing additional analysis or data. This study focuses on the evaluation of landscape metrics as quantitative measures of spatial pattern to describe structures and changes in urban land use in the Santa Barbara, CA region. Urban land cover and land use information were derived from multitemporal, digitally classified airphotos and identify the spatial arrangement of vegetation and built up areas at several test sites through time.

Landscape metrics or indices can be defined as quantitative indices to describe structures and pattern of a landscape (O'Neill et al., 1988; Gustafson and Parker, 1992; McGarigal and Marks, 1994). Their use for describing natural and geographic phenomena is described in Mandelbrot (1983), Goodchild and Mark (1987), DeCola and Lam (1993), and Xia and Clarke (1997). Based on the work of O'Neill (1988), a number of different metrics have been developed, modified and investigated (Li and Reynolds, 1993; McGarigal and Marks, 1994; and Riiters et al., 1995). The most commonly used metrics are the *Contagion Index* and the *Fractal Dimension*. The contagion index describes the fragmentation of a landscape by the random and conditional probabilities that a pixel of a certain patch class (class i) is adjacent pixel to another patch class (class k). The contagion index measures to what extent landscapes are aggregated or clumped (O'Neill 1988). For landscapes consisting of patches of relatively large, less fragmented cover, a high contagion index can be derived. If a landscape is dominated by a relatively greater number of small or highly fragmented patches, the contagion is low.

The fractal dimension describes the complexity and the fragmentation of a patch, by an perimeter-area proportion. Fractal dimension values are typically scaled from +1 to +2; low values are derived when a patch has a compact quadrangular or rectangular form with a relatively small perimeter relative to the area. If the patches are more complex and fragmented, the perimeter increases and yields a higher fractal dimension. In this research, landscape metrics were calculated using the public domain *Fragstats* program (McGarical and Marks, 1994). In addition to the contagion index and the fractal dimension metrics, other, less complex landscape metrics were applied this study. These included percent cover (the percentage of the area covered by a class relative to the total landscape area), patch density, patch size standard deviation, and edge density.

Test areas for this study were selected in different districts of the Santa Barbara, California region. Three sets of color-infrared aerial photographs were identified for use in this study. These photographs were acquired (scale: 1:130.000) by the National Aeronautics and Space Administration and the United States National Aerial Photography Program (NAPP) at scales ranging from 1:40,000 to 1:130,000. Three dates of photographs were chosen: February 1978, November 1988, and May 1998. This data set allowed for a multitemporal analysis covering a ten year time period. These data were first converted from analog to digital form and geometrically corrected and classified. Finally, the required landscape metrics were derived from the classified output images.

To transform the spectral response detected by the remote sensor into thematic information the images were classified by using an unsupervised approach for class division and a visual reclassification in two thematic zones: "vegetation" and "built up". Areas within the classified images were selected as test areas: areas characterized by a single type of urban land use (e.g. commercial, residential) or areas showing a significant change in land cover properties between two dates for comparative analysis. Selected landscape metrics were then calculated from the classified images.

Eight test sites in the Santa Barbara/Goleta, California area were chosen for this study and landscape metrics were computed for each of these test sites. Six of the sites were selected principally for the analysis of urban land use/land cover; the other two sites were chosen in order to study changes in land cover features, i.e. urban growth. Three types of urban land use structures were examined: commercial and industrial; high-density residential; and low-density residential as shown in Table 2.2.7(a).

The three land use categories show a clear difference in the spatial arrangement of "vegetation" and "built up" areas as shown in Figure 2.2.7(a).

Table 2.2.7 (a).

Urban Land Use Structure Type	Name	Test Site Location
Commercial and industrial areas	"commerc"	Two test sites near Goleta airport
High density built up residential areas	"resid(hd)"	Two test sites in Goleta (North and East)
Low density built up residential area	"resid(ld)"	Two test sites in the Hope Ranch area (North and South)

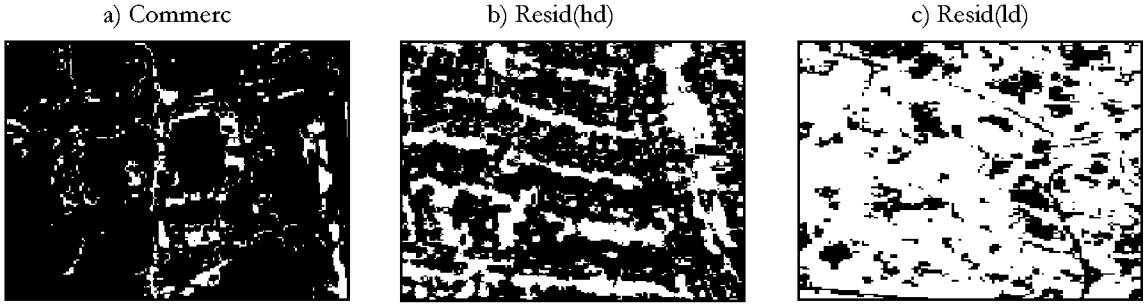


Figure 2.2.7(a): Distribution of vegetation (white) and built up areas (black) in the classified aerial photographs for three different urban land uses.

The metrics calculated from the 1988 and 1998 aerial photography covering the three sets of test sites (commerc, resid(hd), resid(ld)) were compared by mean, minimum and maximum values for different landscape indices (Figure 2.2.7(b). Figure 2.2.7(b) shows the spatial arrangement of vegetation and built up areas for the three cover types in each landscape metric. The percentage of the landscape area (%LAND) areas quantifies the different ratio and dominance of vegetation and built up area for each cover type: with built up area values of approximately .90 for Commerc; .60 for Resid(hd); and .30 for Resid(ld).

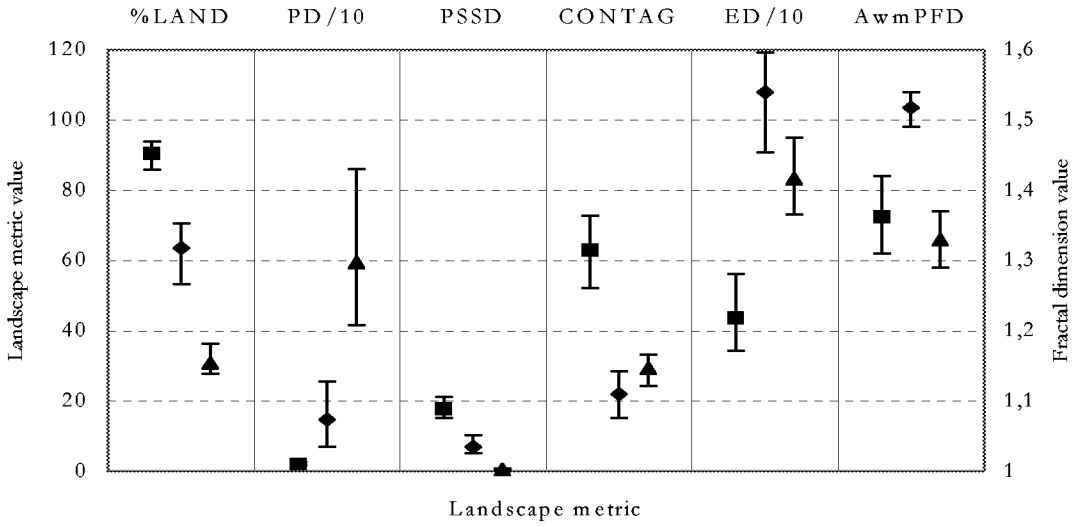


Figure 2.2.7(b). Mean, maximum and minimum values for three urban land use structures derived from 1988 and 1998 classified aerial photographs.

If one reconsider the metric values for the used test sites in Figure 2.2.7(b) it is clear that a description of urban land use structures requires the evaluation of more than one landscape metric; the combination different spatial information (like the percentage of landscape, the spatial aggregation of built up areas or the mean parcel and building size) allows a suggestive separation of these cover types. The different landscape metric should be considered as Landscape Metric Signatures (LMS) for the various urban land use categories.

The further development and testing of these Landscape Metric Signatures will be a focus of our research during the coming year under this research grant.

2.2.8. Statistical Analysis of African Precipitation Data

Extreme precipitation events in Africa can be related to a variety of catastrophic events including drought, famine, flooding, and the spread of disease. Due to a variety of factors, social infrastructure in the regions is generally not in place to alleviate the stress caused by these extreme events, leaving Africa more prone to such precipitation-related disasters. It is important to attempt to anticipate when these extreme events are likely to occur so that disaster relief efforts can be implemented and reduce the potential impacts of these extreme events.

This research is attempting to develop a method for applying the standard precipitation index – SPI, (McKee *et al*, 1993) using historical rainfall records. SPI was introduced by as a method of measuring drought severity for a particular rain station. The SPI attempts to standardize precipitation values in an attempt to calculate a z-score for new values.

For a normal distribution the z-score is the difference of a value from the mean divided by the standard deviation. Previous research looked at historical records for one rainfall station in Colorado and defined drought based on standardized precipitation results for this station. The severity of a particular drought event was based on the z-score for a given period.

The main advantage of the SPI is that it allows for areas with different rainfall regimes to be compared. What constitutes a "drought" in a tropical area might be the same rainfall amount that would be considered "heavy rain" in a desert region. The SPI provides a method for comparing an area against its own history and giving a normalized value to describe the current rainfall conditions. Through this normalization, rainfall values at different locations can be compared.

Traditionally the SPI has been applied to look at long-term drought, leading to distributions that approach normalcy (McKee *et al.*, ibid). However, when looking at rainfall values for shorter periods the values can be better described by the gamma distribution. The gamma distribution uses two parameters to define a statistical probability curve. The alpha parameter describes the shape of the curve. An extremely low alpha value corresponds to a curve that is quite similar to an exponential decay function.

Large alpha values correspond to near-normal distributions. The beta parameter describes the scale of a curve. This coefficient will describe the values associated with the distribution. These two parameters work together to describe a wide array of possible rainfall regimes, making the gamma distribution an intelligent choice for precipitation patterns.

McKee also set up a set of thresholds for classifying a drought according to SPI. SPIs ranging from zero to -0.99 were classified as "mild drought". If the values ranged from -1.0 to -1.49 were classified as a "moderate drought". SPIs from -1.5 to -1.99 were indicative of "severe drought" conditions. Finally, all SPI less than -2.0 were classified as extreme drought conditions. These categories are very broad and may not be applicable in every instance, but for the most part they provide a good framework for the SPI and relate it to terms that people can understand.

Overall the SPI is a good method for evaluation of precipitation conditions at any location with a sufficient rainfall record. Not only does it give a means of comparing a location with it's own history, but it also allows for the comparison of different locations using a normalized scale.

The validity of the SPI is highly dependent on the quality of the input data. This is particularly true of Africa where accurate historical records are difficult to acquire. There are few well-maintained stations and remotely sensed data cannot provide a lengthy enough historical record for application of the SPI. Due to this lack of accurate, spatially and temporally complete data, one is forced to use models to supplement actual data.

The methods for computing the SPI can be applied to any dataset with an extensive historical record. In order to provide reasonable results the data should be at least in monthly increments. However, higher temporal resolution may be desired so that it can be aggregated to any time period of interest. For this study it has been suggested to use 10-day, or decadal, data. The Southern African Development Community (SADC) has used decadal data for their historical precipitation database.

This model uses data from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). These groups have attempted to recreate climatological conditions through a project called the NCEP/NCAR reanalysis. This data represents a rather complete snapshot of various atmospheric properties for any given point in recent history. This model is calculated based on recorded oceanic and atmospheric properties.

The major problem with this data lies in the fact that its resolution is designed for global analysis, but is very coarse when dealing with phenomena on a continental or regional scale. The grid cells of the data are roughly two degrees latitude by two degrees longitude, or approximately 209km x 209km.

This data is used by the UCSB researchers as a primary input into their orographic models. The researchers take the atmospheric properties resulting from the NCEP/NCAR reanalysis data and use those as input into a model that combines this with topographic information to determine how air parcels will move, both vertically and horizontally. This information guides the precipitation estimates and the result is a field of precipitation. The precipitation estimates are then normalized to known station data to ensure that the means in the resulting precipitation field match the station data exactly.

The data developed by this orographic model has, to date, given reasonable results. Comparing the data with the SADC for common points showed that the two data sets are quite comparable, especially during dry months. While the UCSB precipitation estimates are performed for the entire continent the SADC data is only available for Southern Africa. A difference of their means for August is shown in Figure 2.3.8(a).

In addition to having similar results to the average, the UCSB precipitation record seems to pick up the same temporal trends in the historical record as the SADC data. What this means is that periods that are drier than average in the SADC data also appear drier in the UCSB record. This is encouraging because it reveals that the historical record for all of Africa will have a realistic temporal component.

To test the temporal parallels between the two datasets a correlation coefficient for each pixel was calculated based on their common historical records. The results showed good correlation for many points in Southern Africa, with some uncorrelated areas also present. The correlations for August are presented in Figure 2.3.8(b).

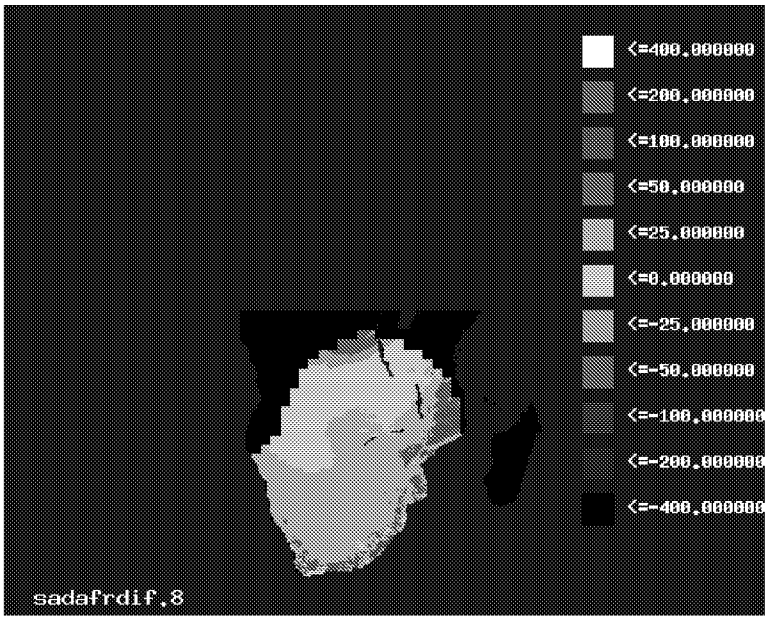


Figure 2.3.8(a). Difference of August averages for SADC and UCSB precipitation data (mm/month).

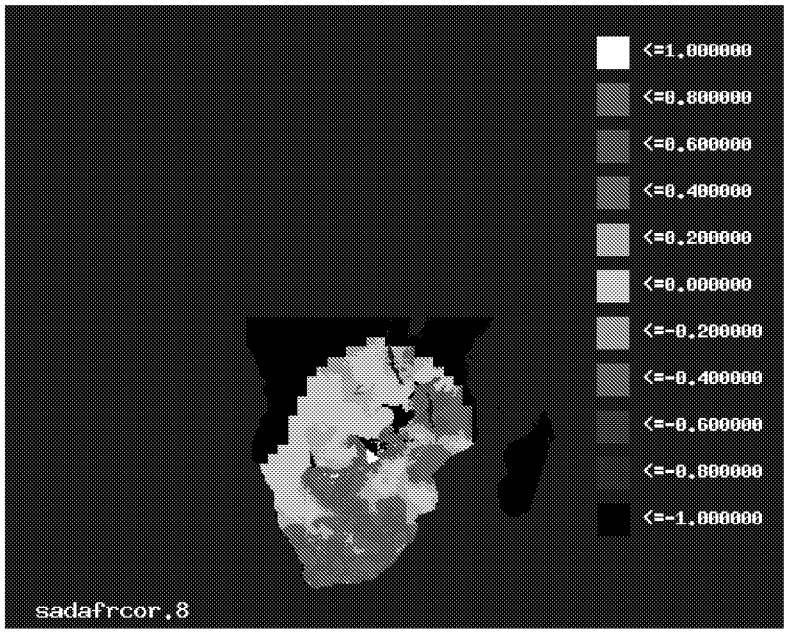


Figure 2.3.8(b). Correlation coefficients between SADC and UCSB precipitation for August historical records.

The first step in calculating the SPI is to develop estimates for the shape and scale parameters for the each point in the grid for the time period of interest, beginning by calculating an intermediary value, A. This is calculated by:

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n}$$

Due to the nature of the gamma distribution values of zero are not included in the calculation of the mean, the number of values (n), or in the summation term. Once this value is calculated, one can begin the calculation of the shape parameter. This parameter is represented by the symbol α, and is calculated by:

$$\alpha = \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right)$$

This value then allows for the calculation of the scale parameter. This parameter is represented by the symbol β, and is calculated by:

$$\beta = \frac{\bar{x}}{\alpha}$$

These parameters have been calculated for preliminary data produced by the UCSB group. To date, only initial exploration of the data has been performed. More extensive analysis will occur when time permits. Presented in Figure 2.3.8(c) and 2.3.8(d) are two January images, one of the shape parameter and one of the scale parameter, for the continent of Africa. These were calculated using January data from 1966 through 1998. Each image is being shown with a unique color table, so values of similar color on different images don't necessarily have the same values.

Figure 2.3.8(c). The shape parameter for January, calculated from the UCSB precipitation estimates.

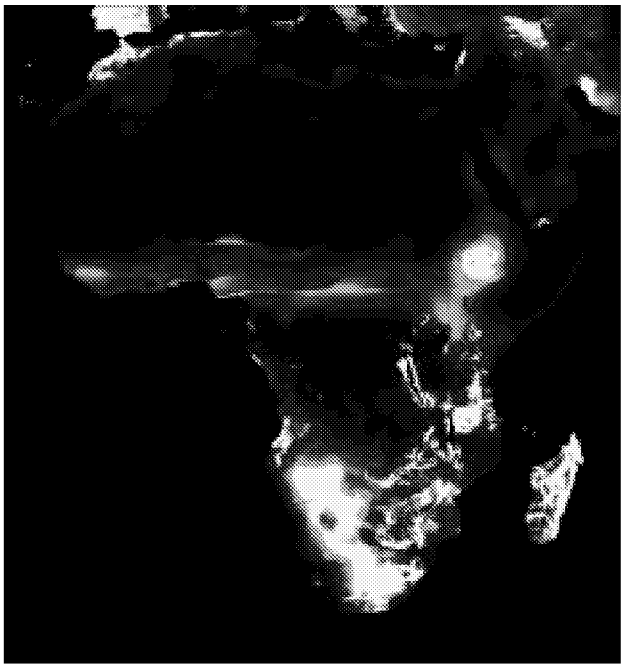


Figure 2.3.8(d). The scale parameter for January, calculate from the UCSB precipitation estimates.

One problem with the calculation of these estimates for the shape and scale parameters is the parameters wind up being highly correlated. As the shape gets extremely large or small, the scale tends to go in the other direction. This negative relationship is clear in the images presented here, with dark areas on one image corresponding to bright areas on the other. This is not desirable, but given the options, this is the best way to estimate the parameters.

These two products have shown some consistencies with the SADC data, enough to provide optimism in the rainfall estimates. The shape and scale results must be investigated further to assess their accuracy and also determine how well they are capturing the different rainfall patterns over the continent. The initial results of this study are encouraging.

2.2.9 Systematic GPS Accuracy Analysis

This study was conducted to determine the affect of common physical structures such as buildings and tree cover on the accuracy of Global Positioning System reception. Additionally, the accuracy of GPS positioning in absence of the Selective Availability function of the GPS satellite system was analyzed.

Until very recently, GPS accuracy has been hindered not only by various environmental factors (such as atmosphere and local topography) but also by the Selective Availability (SA) feature of the GPS satellite system. SA degraded signal quality for the average GPS user to an accuracy of approximately 100m. To improve accuracy, GPS companies developed a system that allowed for a ground station to determine the amount of error associated with both SA and the environmental variables at any given time, and transmit that data via radio beacon to GPS receivers. This special system is referred to as Differential GPS. With the removal of the SA function of the GPS satellite system, GPS users may now find accuracy greatly improved. This research concentrates on the accuracy of GPS units and addresses the question of whether Differential GPS is still necessary in high-accuracy geo-location.

A study area on the University of California at Santa Barbara campus was selected because it contained buildings, tree cover, and relatively open spaces in a heterogeneous mixture (see Figure 2.2.9(a). 75 point locations were randomly generated and then visited using the GPS unit to locate them. At each point location,

the variance in position (an estimator for true accuracy) was measured using the GPS unit with the differential correction feature both on and off.

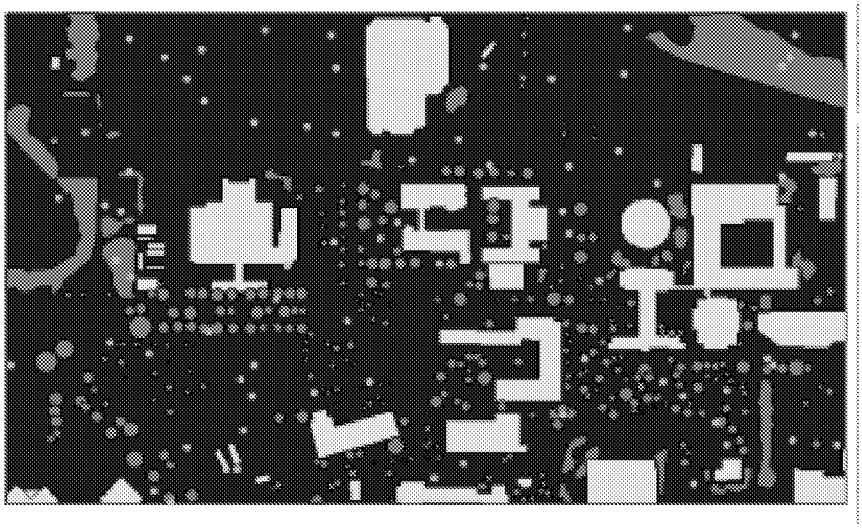


Figure 2.2.9(a). Study Area for GPS Accuracy Assessment - Study Area is bounded by red polygon. Aqua points represent sampling locations. Green polygons are trees, and the gray polygons are the buildings.

To asses the difference in accuracy between using the GPS with and without differential correction, the values were subtracted from each other. This was mapped on the study site using Kriging (see figure 2.2.9(b). Kriging is a method of estimating a value at any location in an area based on values at sample points. At any given location, the values of neighboring known points are interpolated to determine a value (Wang and Zhang, 1999).

Principal components analysis was then performed on the surface estimated in the kriging process. This process by which several different datasets can be evaluated to determine if there is a correlation between one or more of the datasets (Bailey and Gatrell 1999). In this study amount of building volume within 30m of the sample point, amount of tree area within 10m or the sample point, and the variance of the GPS signal were the datasets used for the analysis. Using principal components analysis, it was determined that the primary cause of loss of accuracy with a GPS unit not using differential correction was interference from buildings. Secondarily, there was a strong relation to close proximity to tree cover (<10m). Areas that were relatively free of both buildings and trees show little or no difference in accuracy in using the differential correction signal. In conclusion, Differential GPS may still be a necessary tool for high accuracy geo-location in areas where terrain is not due to buildings, geologic formation, or dense vegetation cover.

As shown in Figure 2.2.9(b), areas in red and yellow indicate areas where differential variance was less than non-differential (yellow is greater value). Areas shown in white are areas where differential and non-differential variances were essentially identical, and blue areas are where differential variance was higher. Trees are digitized in green, and fuchsia polygons are University of California campus buildings.

Using principal components analysis, it was determined that the primary cause of loss of accuracy with a GPS unit not using differential correction was interference from buildings. Secondarily, there was a strong relation to close proximity to tree cover (<10m). Areas that were relatively free of both buildings and trees show little or no difference in accuracy in using the differential correction signal. In conclusion, Differential GPS may still be a necessary tool for high accuracy geo-location in areas where terrain is not due to buildings, geologic formation, or dense vegetation cover.

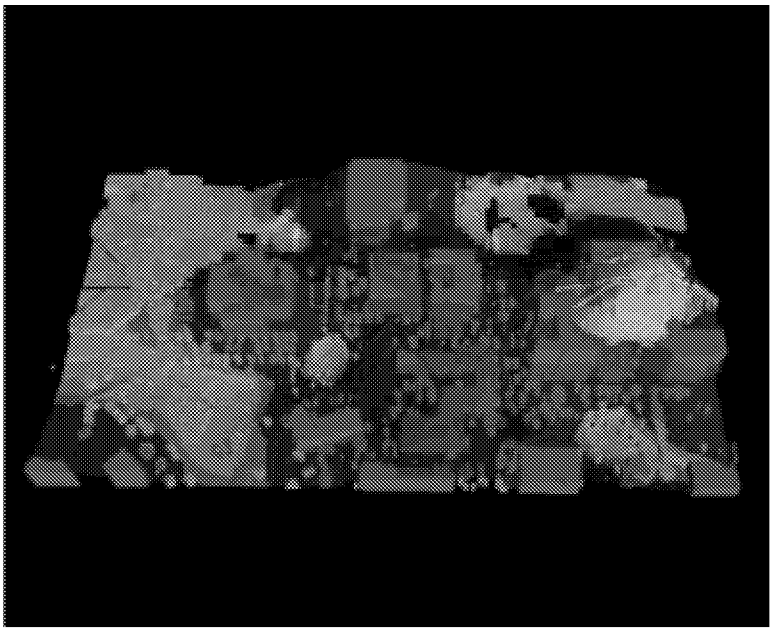


Figure 2.2.9(b). Difference in GPS accuracy with and without differential correction

3. Grant Performance Metrics

ISRG/GSRU researchers continues to forward the transition of Earth Science Enterprise science applications and commercialization results to the broad remote sensing applications user community. We continue to extend our research to address issues related to operational applications. We also reach out to the user community to inform them of the potentials offered by ESE data and information products. Our research is done at many levels from the national and international level, to work at the regional and local level where appropriate. We teach, we train; and we publish, and present the results of our work. Our students graduate and receive degrees. This research will have the goal to demonstrate to the broad user community the operational and commercial potential inherent in the latest OES satellite remote sensing data and information products.

Specific metric goals for each year of this year grant were:

1. A minimum of 3 Papers per year published in reviewed journals and proceedings
2. 1 Masters and/or Doctoral Degree granted
3. Better than 20% annual increases in RSRU world wide website hits
4. Better than 25% increase in downloads from RSRU applications specific sites
5. A 25% increase in tours given of RSRU facilities at the K-12 and higher level
6. Maintenance of our already high level of presentation of grant related material at professional meetings.

Results achieved in meeting these goals are as follows:

1. This funded year ISRG/RSRU researcher published 8 articles in reviewed journals; and 14 proceedings papers/abstracts/presentations.
2. In this grant year we have already graduated 2 Undergraduate Students from our interns, 2 Masters Student and should graduate two more students at the Masters level and three PhD students before the end of the year.
3. Accurate statistics for web hits in 1998 were not available. We know our showing was strong owing to our increase web exposure through contacts at various meetings and our global validation and metrics development efforts. For 1999 through August 18 we have received 2,426 visits to our web page. This includes hits from within the United States and some 17 foreign countries. For the 12 month period from August 1, 1999 to the present, we have had 13,883 web hits from around the world. This is a significant increase.
4. Currently we are in the process of outsourcing our primary distributed dataset, the MAD database. Since this dataset will shortly no longer be distributed by us, we are unaware of the exact number of downloads.
5. This year, to date, the RSRU has conducted some 14 tours, both formal class, "official visitor", and informal drop-in types, of our facilities with an approximate audience count of 200.
6. This year, to date, ISRG/RSRU researchers have made 18 presentations at professional meetings both nationally and internationally. This increase is in part the result of a special session on the validation of the IGBP Global 1km Land Cover Product (DISCover) at the Annual Meetings of the Association of American Geographers in Honolulu, Hawaii in March 1999.

From an analysis of this material we believe we are meeting and exceeding our stated metrics goals. The reader should understand that this is the first year we have attempted to respond to NASA's need and requirement for such information. We will be alert to the need to keep these figures updated at regular intervals.

4. Summary

This document represents the final progress report for National Aeronautics and Space Administration (NASA) Office of Earth Science research grant NAG5-3620, which was awarded in 1999. This grant is titled "Remote Sensing Information Science Research Group" and supported research performed by the Information Sciences Research Group of the Remote Sensing Research Unit (ISRG/RSRU) at the University of California, Santa Barbara (UCSB). This document contains a summary of progress to date for the period 15 December 1999, to 15 March 2001.

The primary research objectives of this NASA grant (NAG5-3620) were to:

- Improve understanding of public sector operational and commercial applications potential of Earth Science Enterprise (ESE) satellite remote sensing data and information.

- Provide outreach to inform the Earth science remote sensing user community, environmental planners, resource managers, educators, public policy decision-makers and the general public of the basic and applied research and public sector and commercial potential of advance satellite remote sensor systems.

- Facilitate the implementation of a broad-based remote sensing applications research program to the benefit of the applications user communities and the public at large, via research, education and outreach.

Under NAG5-3620 ISRG/GSRU researchers have continued to forward the transition of Earth Science results to the broad remote sensing applications user community. We have also extended our research to address issues related to operational applications. Such applications include global Framework data and land cover mapping, biodiversity, and expanded applications and commercial potential of Earth Observing System data. We have also reached out to the user community to inform them of the potentials offered by ESE data and information products. This is done primarily through presentations and discussions at national and international level, although we also worked at the regional, state and local levels where appropriate. Finally, our research had the goal of demonstrating to the broad user community the operational and commercial potential inherent in the latest OES, international, and commercial satellite remote sensing data and information products.

Specific metric goals for each year of this grant include:

1. A minimum of 3 Papers per year published in reviewed journals and proceedings
2. 1 Masters and/or Doctoral Degree granted
3. Better than 20% annual increases in RSRU world wide website hits
4. Better than 25% increase in downloads from RSRU applications specific sites
5. A 25% increase in tours given of RSRU facilities at the K-12 and higher level
6. Maintenance of our already high level of presentation of grant related material at professional meetings.

Results achieved in meeting these goals are as follows:

1. This funded year ISRG/RSRU researcher published 4 articles in reviewed journals, and 18 proceedings papers/abstracts/presentations.
2. In this grant year one RSRU laboratory intern received his undergraduate degree, 3 graduate students received Master of Arts degrees, and 2 received doctorate degrees.
3. Accurate statistics for web hits in 1998 were not available. We are, however confidant that RSRU web exposure has increased through contacts at various meetings, as well as our global validation and metrics development efforts
4. During this period the RSRU conducted some 10 laboratory tours, with an approximate audience count of 100.
5. During this period ISRG/RSRU researchers made 14 presentations at professional meetings both nationally and internationally.

From an analysis of this material it is clear that some annual metrics were met or exceeded, others were not. Decline in some performance metrics is attributed to the decline in the absolute number of RSRU research staff and graduate students due to matriculation.

Faculty, staff, and students at the University of California Santa Barbara conduct ISRG research. Over the past several years our fundamental and applied research has focused on improving our ability to employ advanced information systems with the Landsat and Terra portions of the Earth Observing System (EOS) in the Mission to Planet Earth era. We have expanded this work to include other satellite sensor system that exhibit high applications potential as well. Our goal has been to apply information science techniques and methodologies remains to improve our understanding of the overall potential of EOS and other Earth orbiting satellites for the Earth Science community.

In this task, in previous years researchers in the Washington, D.C. area e.g. W.T. Chen And Company, Inc.; U.S. International Space Year Association (US-ISY); Mezzetti and Associates and, researchers at the University of Maryland, Baltimore County, have assisted us. Mezzetti and Associates and UMBC personnel have worked work with us on various efforts during this reporting period. Our work in the past with UMBC researchers and with Mezzetti and Associates has focused on possible means to extend the applications of EOSDIS data products to a broader user community; and on education related efforts. This user community is the local, state, regional and federal agencies and educators across all fifty states. We currently plan to continue our collaboration with UMBC related personnel in the education arena. We have continued to work with other researches at other institutions e.g. NASA, Stennis Space center, USGS/ EDC, NOAA Coastal Systems center and other academic institutions as appropriate (e.g. the University of New Mexico and Arizona State University).

Specifically, work under this grant, for this reporting period, has focused on fundamental, applications and commercially oriented research, education and capacity building, outreach, and coordination activities directed at improving the use of satellite remotely sensed data and correlative data within an information systems context. We have received funding from the United States Geological Survey to work on Global Map access and availability issues. We have also received funding from Stennis Space Center to help with our evaluation of remote sensing satellite applications readiness in Europe and Asia. With this extension, ISRG/RSRU have continued to work in close collaboration with associated institutions to strengthen and deepen its fundamental and applied information system education, research, dissemination and coordination activities for NASA's Office of Earth Science (OES).

We see this extended applications oriented research program as a logical outgrowth and continuation of the overall ISRG/RSRU efforts aimed at preparing the basic and applied Earth Science remote sensing user community to take full advantage of NASA ESE systems, in particular, the Terra portion of the Earth Observing System. We have also emphasized Landsat and Other governmental and commercial satellite sensor systems in our research as well. Through this work, we have targeted both applied and fundamental research and educational activities. Activities aimed at improving our basic understanding of the role information systems technologies can play in the integration, manipulation, information extraction and analysis, storage, retrieval, and dissemination of remotely sensed data through outreach activities at local, state, regional, national, continental and global scales.

In particular, this year ISRG/RSRU researchers have focused on expanding on the examination of the potential for extending Terra data including Landsat data and EOSDIS services to a broader user communities than global change researchers. This work is an outgrowth of research that was begun five years ago. ISRG/RSRU researchers finalized the publication of the initial potential user model for EOSDIS, which was published by NASA in 1998. In addition, in a past reporting period we received an augmentation to our existing grant for assisting NASA Code YO in the development of the commercial potential of EOS science data products. This work has continued to expand to include our examination of the status of remote sensing applications in both Europe and Asia.

In this rather broad activity area we expanded our examination of the research, development, and applications potential of satellite data products into areas such as agriculture, forestry, rangeland management, urban planning, public health and natural disaster assistance and others. We undertook to understand the unique and or synergistic applications of EOS science and applications data products in these areas. We also continued to

develop and expand our contacts with private industry and with the international user community. We have, in particular, sought the opinions of potential high-resolution, data providers, value-added firms, and data producers. We have also examined the ways in which the market for commercial remote sensing data products is developing both in the U.S. and abroad, and tried to identify ways in which these commercial system products can be augmented by EOS (in particular Terra and Landsat 7, ETM+) data and information products. We also expanded our ongoing research examining how commercial satellite data and information products can be employed in support of ESE science and applications research objectives.

We undertook to integrate this information into an examination of alternative scenarios for applications development within NASA, and provide insight into several significant questions:

- How do we move from science results to applications and commercialization in an efficient and an effective manner?
- How much applications oriented research is being supported by the NASA Earth Science Applications Commercialization and Education Division?
- How can we measure progress and increase outreach in NASA applied remote sensing activities?
- What are appropriate metrics for establishing progress in these areas?

All these are policy-related questions have been the focus of graduate student research in this grant period.

During this reporting period we have been working on upgrading the methodology employed in the validation of the International Geosphere Biosphere Program's (IGBP) DISCover Global 1 Kilometer land cover product.

ISRG/RSRU research has continued to emphasize information systems as research, outreach and as educational technologies; technologies capable of improving dissemination of NASA data and information to a broad user community from the scientific, planning, and policy arena to the public sector applied and commercial communities. We have also focused on improving ways to deliver these data to those in private industry that may add value to it and to better distribute these data to the citizen in the street as well as the student in the classroom. Information systems can improve our ability to evaluate the utility of NASA Earth Science data and information in a variety of ways. Working on information from meetings held by ISRG/RSRU researchers in conjunction with UCSB's National Center for Geographic Information and Analysis, we have continued the development of a series of papers, books, instructional volumes, and associated curriculum in remote sensing. This work emphasizes the integration of remote sensing and geographic information systems. Some of this material has been added to the NCGIA core curriculum of which hundreds of copies have been distributed to educational institutions across the United States, and to more than 70 foreign countries.

Just as in past years, ISRG/RSRU continued to receive funds from other NASA Codes and from other federal and international agencies to supplement ISRG activities. These funds cover a range of tasks. During this reporting period we received support from NASA Stennis Space center to support of our applications evaluation efforts. We have continued to receive funding from the USGS to support our work on global map development (a research area with particular relevance to NASA's Digital Earth effort). We have also strengthened our ties in the commercial sector; particularly with MapFactory-HJW, and Globexplorer.com.

Dr. Estes' work on the Space Station Utilization Advisory Subcommittee (SSUAS) has grown in importance in the Earth sciences with the addition of the Russian Space Agency (RSA) to the International Space station effort. Attached payloads accommodation and the addition of an optical quality window (now named the Window Observational Rack Facility [WORF]) are major additions of interest to the observing and sensing science community. Until his death, Dr. Estes was the longest serving member of SSUAS. It is his work with this committee and with the IGBP DISCover project and the NASA Headquarters and Johnson Space Center supported land cover validation efforts that have lead to our work on the uses of Shuttle and International Space Station. This work can be of real benefit as we seek to validate a variety of land cover products and expand the overall applied uses of Space Station resources.

UCSB was designated by the National Science Foundation as the National Center for Geographic Information and Analysis (NCGIA). NCGIA has recently been redirected by the National Science Foundation to address a

broader number of issues and has been recast under the new name of Project Varenius. The work of the Center significantly complements and added supplemental funding to a number of the efforts reported under this grant. In addition, our participation in work for UNEP, UNDP, UNESCO, UNITAR, SCOPE, ISCGM and GSDI has been subsidized by these organizations and related organizations. In addition, ISRG/RSRU researchers have worked on core data related issues under UNDP funding through USRA. To date, this support included travel support to attend meetings of various advisory committees and working groups, as well as the provision of secretarial and production services as required by these activities.

We continue to work with the United States Geological Survey's (USGS) EROS Data Center (EDC) in a variety of areas. At present these areas are focused around the National Land Remote Sensing Data Archive and in the Global Mapping area. The Consortium of International Earth Science Information Networks (CIESIN) continued to have close association with ISRG personnel. We continued to expand our work on the fundamental and applied research, educational and outreach aspects of the human dimensions of global change and continued work with NCGIA and the National Academy of Science's Human Dimensions of Global Change Committee. Dr. Estes also worked on the UCSB Consortium effort for the United States Department of Transportation.

An increasing world population continues to put pressure on our global resource base. This increased pressure requires that we come to an improved understanding of the factors that influence change in the Earth system. It also requires that we seek new and improved ways that we can employ remotely sensed data to promote economic growth within the context of sustainable economic development and more livable communities. Research in both of these areas must not only be focused on specifics and processes but on increasing both fundamental and applied understanding. The material proposed herein summarizes our attempts to address scientific issues with a mix of both applied and fundamental research. We believe that the results of this research will aid earth system scientists, commercial vendors, entrepreneurs, environmental planners, resource managers, and public policy makers at Local, State, National, Regional and Global levels to more fully appreciate the potential of remotely sensed data. Such understanding will expand the range of applications of remote sensing, help create a more robust commercial remote sensing enterprise in the United States and advance the development and enhance the availability of geospatial information technologies and data and information products for the benefit of future generations.

5. Vitae of Key Participants

5.1. John E. Estes (deceased)

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Education

1959 A.A., San Diego Junior College - Social Science
1962 B.A., San Diego State College - Geography/Geology
1963 M.A., San Diego State College - Geography
1969 Ph.D., University of California, Los Angeles - Geography

Employment

1979 - Present: Professor of Geography, University of California, Santa Barbara
1992-95: Director/Senior Visiting Scientist, Universities Earth Sciences Program, Universities Space Research Association, Coordination between NASA, OMTPE and USGS, NMD
1987 - 89: Visiting Scientist NASA Headquarters
1984: Instructor: Continuing Engineering Education, George Washington University
1978: Scientist: Joint appointment California Inst. of Tech./JPL and UC, Santa Barbara
1975: Associate Professor of Geography, University of California, Santa Barbara
1969-75: Assistant Professor of Geography, University of California, Santa Barbara
1969: Research Associate, School of Forestry, University of California, Berkeley
1969: Lecturer in Geography, University of California, Santa Barbara
1965-69: Research Assistant, University of California
1964-65: Geographer, Texas Instruments Incorporated

Honors And Awards:

- NDEA Title IV Fellowship - 1965-1968 for Ph.D., Dept. of Geog. UCLA
- National Merit Teachers Award, National Council on Geographic Education, October, 1975.
- American Soc. of Photogrammetry, Presidential Citation for Meritorious Service, March, 1976.
- Who's Who in the West, 1976, 1977.
- Notable Americans Award 1976-1977, 1978-1979.
- Distinguished and Outstanding Personalities of the West and Midwest, 1977, 1978.
- International Who's Who in Community Service, 1978.
- NASA Group Achievement Award for LACIE Project Team Participation, 1980.
- ASP Award 3rd Place Award 1980 for Outstanding Applications Paper.
- American Society of Photogrammetry, 1981 Ford Bartlett Award.
- American Society of Photogrammety, 1983, Certificate of Appreciation.
- American Society of Photogrammetry, 1984, Presidential Citation for Meritorious Service.
- Honorary Chief Editor GeoCarto International 1989-1990.
- Certificate of Appreciation for Outstanding Service, Space Applications Board, Commission on Engineering and Technical Systems, National Research Council, 1988/89.
- Remote Sensing Medal, AAG, Remote Sensing Specialty Group, 1994.
- Elected, Fellow of the American Society of Photogrammetry, 1994.
- American Society of Photogrammetry Certificate of Appreciation for Meritorious Service,1994

- Interviewed for the Geographers on Film Series, Assoc. of American Geographers, 1995.
- NASA, Commendation for Contributions to Mission to Planet Earth, 1996.
- Elected Chair, International Steering Committee for Global Mapping, 1996.
- SPOT Image Academic Advisory Committee, 1996 – Present.
- NASA, Code Y, 1997 Rotary Stellar Award Nominee, 1997
- International Astronautical Federation, Certificate of Appreciation, "For outstanding contribution" 1998.
- GSDI, Certificate of Appreciation, Third Global Spatial Data Infrastructure Conference, 1998.
- NASA, Space Station Program Office, Team Excellence Award, 1999.
- Association of American Geographers, Lifetime Achievement Honors, 1999.

Selected Professional Activities (since 1992 only)

- Member, NASA, Space Station Utilization Advisory Sub-committee, NASA, 1988-present.
- Reviewer, Energy Collaborative Research Awards Proposals, State of Maine, October 1992,
- Member, Graduate Review Team: Dept. of Geog., Univ. of New Mexico, Albuquerque, 10/92.
- Member, USEPA/NASA/USGS North America Landcover Project Peer Review Team, 92-95.
- Chairman, NCGIA/EOSAT Remote Sensing/Curriculum Development Project, 1992-95
- Co-chair, Aspen Global Change Inst. Workshop, Early Detection of Global Change, Aug., 1993.
- Chair, Review Panel EPA/EMAP, Landscape Characterization Program Plan Review, 1993.
- Member, Peer Review Panel for Space Science Computing Division, NASA/GSFC, 1993.
- Member, External Review Committee, Department of Geography, University of Maryland, 1994.
- Member of GTOS/GCOS, Joint Review Panel, 1994.
- Chair, Steering Committee, International Symposium on Core Data Needs for Environmental Assessment and Sustainable Development Strategies, 1994 - 1995.
- Member, IGBP, Validation Working Group, 1km Land Cover Classification Project, 94 - Present.
- Invited Participant, GLOBE Science Workshop, Aspen Global Change Institute, 1994.
- Chair, Socio-economic Distributed Active Archive (SEDAC), User Working Group, 94-99 (now member).
- Member, Earth Obs. Committee of the International Astronautics Federation, 94-99.
- Member, NOAA, Coastal Change Analysis Program (C-CAP), Peer Review Committee, 1994/5.
- Co-Chair, NASA, EOS/Data and Information System, Potential User Model Study, 1994.
- Invited Participant, International Research Cooperation on Space Station Meeting, Sponsored by the International Forum on the Scientific Uses of Space Station, 1995-Present.
- Chair, International Steering Committee for Global Mapping 1995-Present.
- Member, Nat. Res. Council, Commission Physical Sciences, Mathematics and Applications, 1996-1999.
- Chairman, IGBP Validation Working Group, IGBP-DIS Land Cover Working Group, 1997-Present.
- Member, IGBP-DIS Land Cover Working Group, 1997- present.
- Member, NASA, Earth System Science Advisory Committee, 1997 – 2001.
- Member, Executive Committee, Global Spatial Data Infrastructure Effort 1998-Present.
- Chair, NASA Applications Steering Committee, 1998 – Present.

Extramural Support (PI listing only since 1992):

1. "Migration of Scientific Information into Decision-Making", 1992, CIESIN, $309,936.
2. "Survey of Applied Remote Sensing Technology in the US", 1992, Telespazio, $35,028.
3. "Wetnet", 1992-93, NASA, $74,996.
4. "Remote Sensing Information Science Research", 1992-93, NASA, $1,206,216.
5. "Modelling Land Use Change in Brazil/Rondonia", 1992-93, UC CalSpace Institute, $25,000.
6. "Improved Integration of Remote Sensing Imagery with GIS", 10/1/92-1/15/93, EG&G, $49,793.
7. "Migration of Sci. Info. into the Decision-making Arena",5/1/92-4/30/93, CIESIN, $196,436.
8. "Wetnet", 7/20/92-7/19/93, NASA, $74,996.
9. "Advanced Remote Sensing and GIS Integration Demo. and Basic Research, 11/18/92-11/17/94, EPA, $35,000.

10. "Remote Sensing Information Science Research Group", 5/93/494, NASA, $940,932.
11. "Information Science Research Support and Coordination for Global Science in the EOS Era", 10/94 - 9/95, NASA, $462,300.
12. "Fellowship Grant for G. Menz", Max Kade Foundation, 3/95 - 9/95, $16,825.
13. "Remote Sensing Information Science Research Group", 10/95 - 9/96, NASA, $659,987.
14. "Remote Sensing Study of Historical Changes in Natural Oil Slick Volumes in Santa Barbara Channel", UC Energy Institute, 7/95 - 6/96. $21,000.
15. "Remote Sensing Core Cirriculum Development", Univ. of Maryland, Baltimore, County, Sub from NASA Contract, 5/95 - 4/97, $13,221.
16. National Center for Geographic Information and Analysis, Mike Goodchild (PI) and other Co-PIs, 1/96 - 12/97, NSF, $1,199,970 (Year 8, cumulative amt. awarded total $9,413,469).
17. "Remote Sensing Core Cirriculum Development", Univ, of Maryland, Baltimore, County, Sub from NASA Contract, 5/96 - 4/97, $19,222.
18. "Conduct of Info Sci Res Related to the Dev of an EOSDIS User Model", 10/94 - 9/95, NASA, $123,746.
19. Advancing Geographic Info Science, M. Goodchild (PI) & other Co-PIs, 2/97 - 1/00, NSF, $2,299,774.
20. "Support for UN Global Mapping Conference", USGS, 10/96 - 2/97, $5,000.
21. "Remote Sensing Information Science Research Group", 12/96 - 12/97, NASA, $499,985.
22. "Accuracy Assessment of IGBP Fast Track 1km. Land Cover Data Set" 5/97- 10/98, NASA, $260,000.
23. "Accuracy Assessment of IGBP Fast Track 1km. Land Cover Data Set" 11/98 - 4/99, $70,000.
24. "Remote Sensing Information Science Research Group", 12/97 - 12/98, NASA, $499,900.
25. "Remote Sensing Information Science Research Group", (Supplement) 9/98 - 7/99, NASA, $290,808.
26. "Remote Sensing Information Science Research Group", 12/98 - 12/99, NASA, $500,000.
27. "Global Mapping Project", 3/99-12/99, USGS, $49,204.

Selected Publications (from over 350)

Estes, J.E., and L.W. Senger, (Eds.), 1974, Remote Sensing: Techniques for Environmental Analysis, Santa Barbara, California, Hamilton Publishing Co., 340 pp.

Estes, John E., and D.S. Simonett, 1975, Author-Editors of Chapter 14, "Fundamentals of Image Interpretation", in R.G. Reeves (Ed.), Manual of Remote Sensing, Vol. II, American Society of Photogrammetry, Falls Church, VA, pp. 869-1076.

Estes, J.E., and G.A. Thorley (Eds.), 1983, Manual of Remote Sensing , Second Edition: Volume II. American Society of Photogrammetry and Remote Sensing, Falls Church, VA. pp. 1233-2440.

Estes, J.E., E.J. Hajic, and L.R. Tinney, author-editors, 1983. "Fundamentals of Image Analysis of Visible and Infrared Regions", Chapter 24 in Manual of Remote Sensing, 2nd ed., Vol. I., Falls Church, VA, Am. Soc. of Photogrammetry, pp. 987-1124.

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176C, Application Issues in Geographic Information Systems;
184A, Introduction to Cartographic Programming;
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